PUBLISHER'S COLUMN

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We are often asked by authors and advertisers when our 'deadline' is—that is, the last possible date on which we can receive material for inclusion in the current issue. This is sometimes very difficult to give precisely and so they are justifiably rather mystified. So let us have a look at how a magazine is actually produced.

First, a journal like **CONTROL** is physically composed of groups of 16 pages which are all printed on one side of a sheet of paper—eight pages on both sides. This particular issue consists of seven of these groups, or signatures as the printers call them. When all the sheets are printed they are folded and then stapled—or 'stabbed'—together in the correct order. The cover, already printed, is now glued onto the spine and the complete magazine guillotined to the correct size, which of course removes the folds in the sheets and allows the pages to turn.

Now generally there are only one or two machines available for printing and obviously the sheets have to run in rotation. A further complication is that some sheets may have two or more colours and this means further trips through the press. It can easily be seen therefore that in a magazine the size of **CONTROL** some sheets have to be passed for press long before others and so unless we know exactly where an article is going in the magazine it is impossible to give a firm date. Of course for the great majority of pages we do know this and there is no difficulty. But until the magazine has been completely paginated there is always an element of doubt as to where some items are going.

Particularly with editorial matter, until we receive the manuscript we are not sure of the best position for the article but until we know where it's going we cannot give the deadline to a day. That's why we always like if possible to receive manuscripts on the day we get the previous issue off our chests.

CONTROL

SEPTEMBER 1958 VOLUME 1 NUMBER 3

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CONTROL SEPTEMBER 1958 VOL 1 NO 3

Detective issue

No one with any engineering knowledge would think about controlling plant automatically without providing means of measurement. But it is unfortunate that, with present knowledge of many industrial processes, engineers who design control systems for them cannot tell what are really the most important measurements and where they should be made. Often design can be based only on what has worked before in similar plants, with perhaps one or two experimental excursions into control by a less used physical parameter such as electrical conductivity. Particularly is this true of chemical processes, where control commonly depends on measuring and regulating physical parameters such as flow, level, pressure and temperature. More economic and efficient control could probably be obtained by continuous chemical analysis, but the results must be translated into terms of regulating physical parameters, which include flow of raw materials. In fact, as Mr Pamely-Evans points out in an article in this issue, nearly all of what engineers call 'process control' should be termed 'plant control'. At present process industries are only on the outer fringe of real process control, or 'quality control'; some progress is being achieved by, for example, measurement of hydrogen-ion exponent of liquids and by oxygen analysis of gases—but very rarely are these chemical measurements used for continuous automatic control. To use them effectively, we must, as Mr Davis points out in this month's *Industry's Viewpoint*, 'know far more about the dynamics of process plant than we do at the moment'.

This then is one problem facing plant designers today—deciding what parameters to measure for producing effective control signals. A second problem follows—having chosen a parameter how best to measure it. Usually the choice of method is not obvious even if the decision between electrical and pneumatic signals has already been made; for example there exists a wide variety of methods of measuring temperature and flow.

In assessing methods of measuring parameters, the control engineer must look to the scientific basis of detectors, since before he can measure he must detect. All detecting instruments are transducers, that is devices which change energy from one form to another, although the converse is not true. In this issue appears the first of a series of short articles on transducers. It is written by Dr J. Thomson, Director of the British Scientific Instrument Research Association, and succeeding articles will be by members of his staff. Dr Thomson considers the fundamental question of energy change for detection from a scientific standpoint, and he includes an intriguing chart showing present possible methods of interchanging the major forms of energy.

Intended both for reference and providing ideas is a second chart published in this issue as a Data Sheet. This summarizes most of the known methods of detecting physical parameters by direct conversion to various types of electrical signals—in effect the background of single-stage electrical transducers. Many gaps exist in this chart but they do not usually represent deficiencies in present measurement techniques, since often double- or triple-stage instruments will fill them (e.g. a hinged-vane flowmeter coupled to a synchro would give a conversion from variable flow rate to variable inductance). Nevertheless the gaps are thought-provoking, and so is the absence of parameters such as angular acceleration and surface quality since they cannot at present be detected electrically by a single-stage conversion.

Transducers are fundamental to control. As autocontrol of industrial plant and processes spreads, control engineers will need to improve existing transducers and develop new ones. We believe that this series of articles by the BSIRA staff will be helpful to them in showing what present detecting devices can do and in pointing to ways along which future development might progress.

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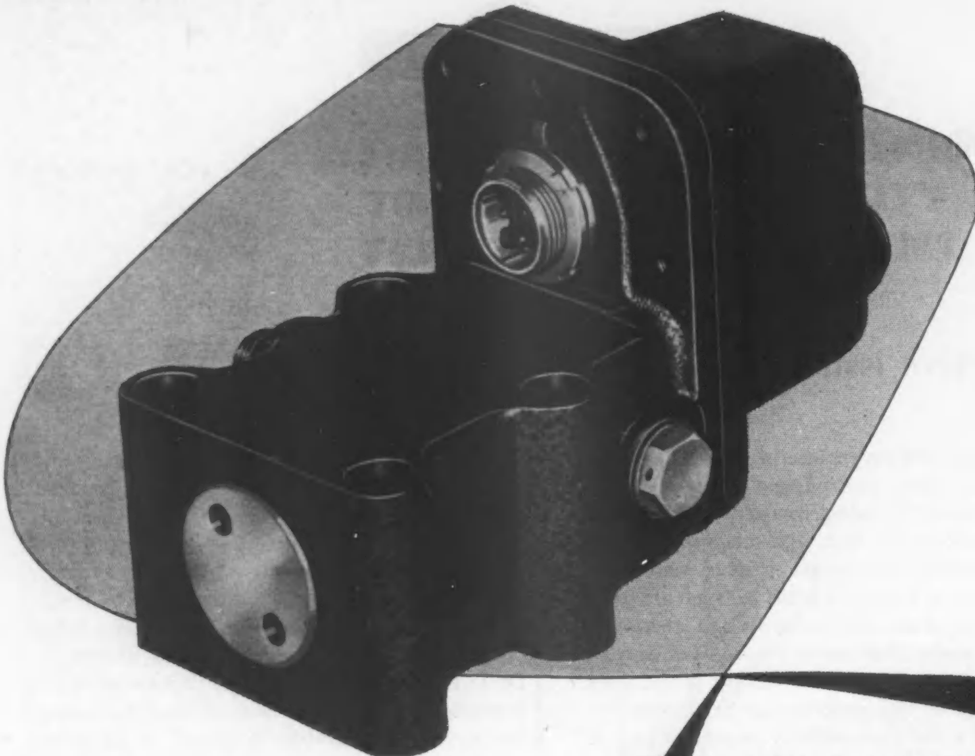

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SIR! LETTERS TO CONTROL

The Editor welcomes correspondence for publication

Servo stories—without mathematical frolics

SIR: I hope very much that CONTROL will take the fullest advantage of its great possibilities as a forum for the wide dissemination of servomechanism lore to older practising engineers. In my view too many engineers tend to regard this as a specialized sphere to be left to the mathematically inclined, and I think that the latter have been so fascinated by the subject that they have passed rather too quickly to the study of newer aspects, such as sampling servos and non-linear servos, without paying quite enough attention to the full propagation of knowledge on the basic requirement for high gain, accurate, smoothly following servos. The attraction of methods of analysis based on the response to step functions may also have tended to concentrate attention on servo behaviour at very large misalignments, and this philosophy may account for the many small or medium-size servos which are admirably suited to run smartly into line from impossibly wrong directions, but which are jittery when they get there. From my limited observation, process control engineers are in a somewhat happier position. Their systems appear to be based more solidly on the need to maintain a close control on the process within narrow limits, with rather less emphasis on a maximum speed of return after control is lost.

I believe that much good can be done by a consideration in general terms of the various available methods of servo stabilization with particular attention to the physical mode in which they operate on the system, and to the ways in which they can contribute to highly accurate, well-damped following systems.

I hope that your journal will, in physical rather than mathematical terms, inform engineers in general about the many servo systems which have come into prominence since the days of their formal education.

Ealing W. T. JOHNSON

● *We shall do our best to do so. We shall always be glad to receive authoritative articles giving physical interpretations of practical servo systems. Probably the Services could provide some useful accounts of this kind, for they have used servos as long as anyone in this country*—EDITOR

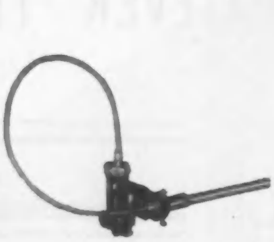
Reliability through simplicity

SIR: From some of the systems described in the first issue of CONTROL, it is obvious that the reliability of electronic control systems must in practice be as high as possible. A failure of any component in the chain could produce disastrous results in, for instance, an electronically controlled profiling machine.

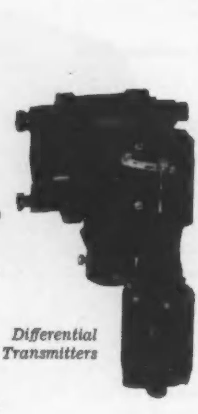
The relative advantages of mechanical controls and electronic controls might well be the subject of a future article in your magazine, but the point of this letter is to draw attention to the requirements for maximum reliability in components used in electronic circuits for control equipment.

Reliability studies have shown that the failure rate of electronic components when operated under reasonable conditions in this country is of the order of 0·01—0·1 pc per 1000 hours of operation. But a complex control equipment requires a very much higher order of *individual* component reliability than one using a smaller total number of components. Simplicity in design, therefore, is

Not only



Temperature Transmitters



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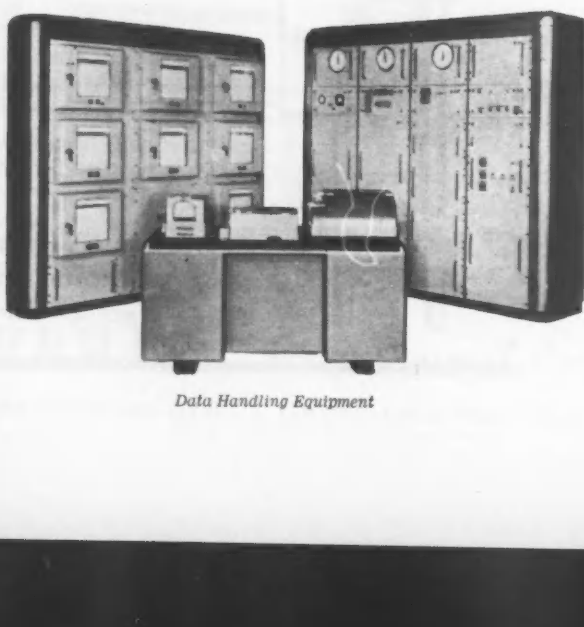

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essential and all control design engineers would be wise to devote much time to striving for it in their electronic control circuits.

Protection of components from the damaging effects of moisture, shock, vibration, industrial pollution, etc, is also vital. The failure rate of components under protected conditions is approximately one-tenth to one-twentieth of that of those operated under arduous conditions such as obtain in the Armed Forces. Adequate humidity, vibration proofing, etc, of equipment is well worth while.

It would be interesting to hear of experiences in industrial control equipment of the reliability actually achieved under typical working conditions. A great deal is being done to reduce faults occurring, but case histories would prove useful in assessing the actual reliability achieved in control circuits.

Royal Radar Establishment, Malvern G. W. A. DUMMER

● *Reliability is the linchpin of the present controversy about the use of electronic control in industry (though our contributors Mr Needham and Mr Pamely-Evans find plenty of other points for and against it on other pages of this issue). Let us hear what is being realized in practice. Please send some case histories, as Mr Dummer suggests, and we will print them*—EDITOR

What do the users need?

SIR: Three things impress me in the way you have rung the bell in the first issue of CONTROL. First the fact that all your articles are written by experts in their subjects, secondly the attempt to initiate a series of most valuable classified tables and lastly the provision of an organized reader information service.

If you can adhere to your self-imposed standards of technical excellence your journal can play a very important part in focusing real control know-how.

In your first issue you concentrate on making a positive contribution to theory and hardware information. I suggest you occasionally invite articles from engineers having a strictly user interest and who can state their unsolved problems in common-sense language. A survey of control *requirements* over our forty or fifty user industrial groups would give a balance to the picture which not only would sustain interest but is an urgent requirement.

Ealing DAVID FOSTER

● *We are trying to maintain a useful balance between articles for the control engineer and for the user, and we hope Dr Foster has found a little more of user interest in the most recent issues. His point about industrial requirements is most cogent, and we intend to publish surveys of these for particular industries*—EDITOR

An advertising correction

SIR: We regret that the text of the advertisement of our clients, the Palatine Tool & Engineering Co (Surbiton) Ltd on p A46 of your August issue is not quite accurate. Our clients have advised us that although produced by themselves the instrument featured was in fact *designed* by A. Frazer-Nash (Engineering Section) for the UKAEA.

London WEBSTER RIDGWAY & PARTNERS LTD
Advertising agents

A monthly article by a prominent man in the control industry on a subject chosen by himself

A NEW CONCEPT

by **N. RYLAND DAVIS**, M.A., M.I.E.E., F.Inst.P.
Managing Director, Sunvic Controls Ltd

The concept of control, and particularly process control, which I wish briefly to consider, has undergone a fundamental change in the last decade.

This change has been brought about by the development of end-product analysers, high-speed monitoring equipment, and the growing application of digital and analogue computers.

We are approaching the idea of a large plant, e.g. an oil refinery or even a series of oil refineries, together with ancillary chemical plant for the production of synthetic rubber or other products, containing some hundreds of control points, some thousands of measuring points and many end-product analysers.

The whole plant will be continuously monitored, and printed or punched-card records made of its performance. A specially designed computer will seek out the optimum setting of the plant parameters under all conditions in order to produce a quality of product or collection of products to meet the day-to-day market conditions.

Such a project could hardly appear as a complete entity: it will emerge after a long and carefully planned process of evolution in which the designer and the user must cooperate closely. To design such a system, we should have to make extensive use of electrical and electronic techniques for the transmission and storage of vast quantities of data. We should have to develop sensing elements of faster response and higher accuracy than those commonly available today. We should require to know far more about the dynamics of process plant than we do at the moment. This constitutes a major research and development project.

Large-scale experiments on these lines are already under way in both Russia and America, and, if England is to keep her place in the forefront of technical progress, not only will similar plants have to be erected in this country, but many more control engineers will have to be trained to design and operate the next generation of chemical factories.

Sir Harold Hartley in his recent presidential address to the Society of Instrument Technology made a forceful plea for the establishment of control engineering as a separate technological discipline. If CONTROL, through its editorial policy and the quality of its technical articles, can bring nearer the day when this new technology emerges as an organized study, it will have made a lasting contribution to Britain's industrial potential.

Electronics can do everything in process control that pneumatics can
—says Maurice Needham

ELECTRONIC SYSTEMS FOR INDUSTRIAL MEASUREMENT AND CONTROL—3

by **M. V. NEEDHAM**, *Assistant General Manager (Industrial), Elliott Brothers (London) Ltd*

The concluding part of an article whose first two parts appeared in the July and August issues

5.3 Manual control

Manual setting, of the current to the electropneumatic valve or convertor, is provided by a unit fitted in the recorder case or separately on the control panel. It provides a variable direct current of 1–5 mA and the switching arrangements allow for 'bump-less' change-over.

The d.c. is provided by a simple half-wave rectifier fed from the mains voltage, and its value is adjusted by means of a variable series resistor and indicated on a milliammeter calibrated in valve position. Fig. 21 shows the manual control unit and Fig. 22 shows the function of the switch.

Position 1: *Unlock*. The power is disconnected from the manual unit, which can be safely withdrawn for servicing if necessary.

Position 2: *Automatic*. The system is under automatic control, with the manual control current flowing in a dummy load equal to that of the control element. The meter shows valve position.

Position 3: *Auto-balance*. The controller output flows in the control element and the manual control current in the dummy load is indicated on the meter.

Position 4: *Manual*. The controller output flows in the dummy load and the manual control current flows in the control element via the meter. The feedback network of the automatic reset unit remains connected to the control element.

Position 5: *Manual balance*. The controller current flows in the dummy load via the meter and manual control current flows in the control element.

Change-over from Automatic to Manual control. In the *Automatic* position (2) the system is in control with the recorder pen and set-point pointer aligned, and a certain valve position is indicated by the meter. This position is noted and the switch changed to *Auto-balance* (3). In this position the manual control current can be adjusted, so that the meter indicates the original valve position, after which the switch can be moved to *Manual* (4) with no control disturbance.

Change-over from Manual to Automatic control. The valve position is noted and the switch changed to *Manual balance* (5). The set point is then adjusted until the meter indicates the manual control position. After a few seconds' delay, to allow the capacitor in the reset network to charge fully, the switch is put directly to *Automatic* and the system comes under automatic control without disturbance.

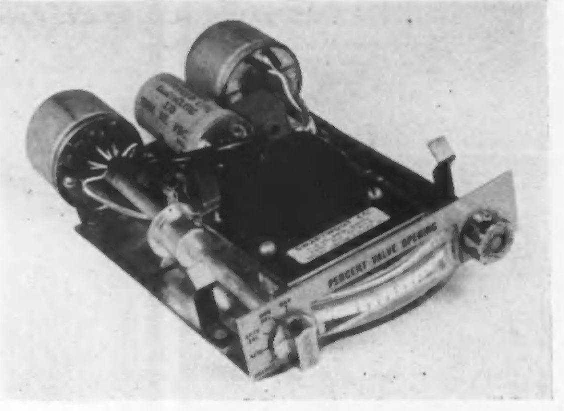

Fig. 21 The manual unit for the electronic controller which can be mounted in the miniature recorder case

6. The a.c. system in operation

Although the electronic systems, such as that described here, are of recent origin, the range of application is already wide. The selection of examples quoted in the following serve to show some of the practical details involved and indicate the flexibility of the techniques.

6.1 Flow control

Simple flow control loops form a large fraction of process applications. The equipment used in a typical case is shown in Fig. 23. An orifice plate or venturi of conventional type is used with a displacement-type differential-pressure transmitter. The supply for the differential transformer in this transmitter is derived from the recorder-controller and conveyed in a four-core cable together with the transmitter output signal. If a local indication is required an instrument, such as that described in Section 4.2, can be used. Since the controller is mounted on the back of the recorder, containing the auto-manual unit, panel space and cabling are both minimized.

In all critical units, such as controllers, the valves are run with reduced heater voltage which prolongs their life considerably. The substantially steady supply from the constant

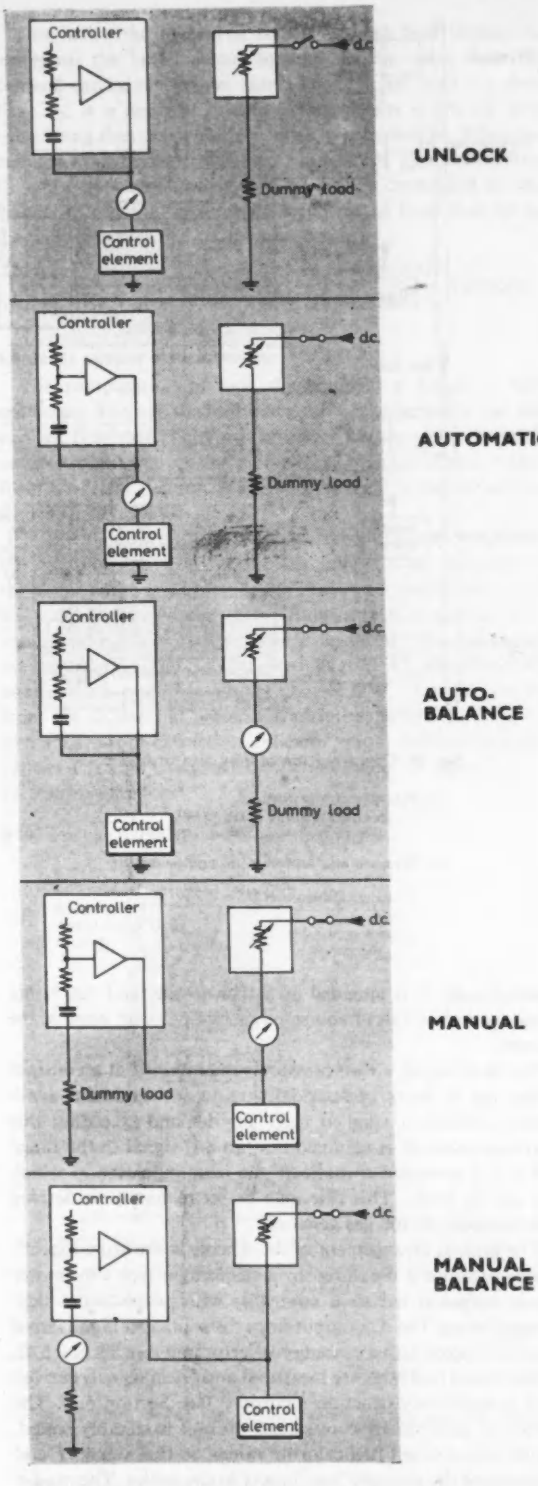

Fig. 22 Manual control unit—switching

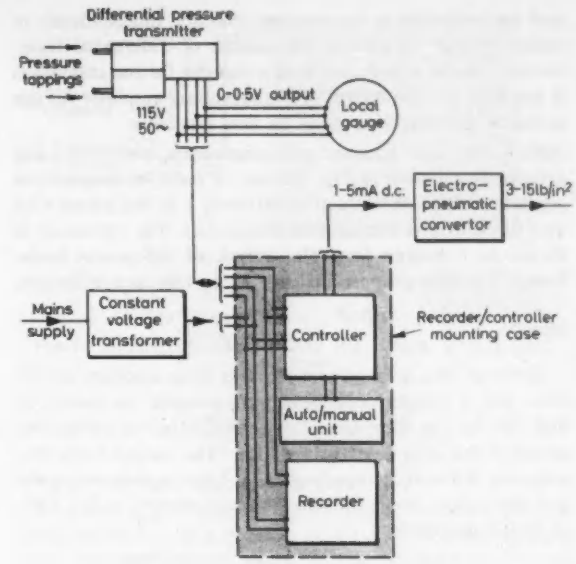

Fig. 23 Flow control loop

voltage transformer also helps considerably in this. However it is to be emphasized that this constant voltage supply is not essential to the attainment of instrumental accuracy since the system is a null-balance one. There is complete compensation for supply voltage variations, as explained in Section 4.2. Where a large amount of equipment is installed one constant voltage supply is normally used.

In some instances local indication, independent of the telemetering system, is required. A convenient arrangement is based on the use of a filled bellows type of flowmeter such as the International Instrument Corporation instrument. The output from this is a shaft rotation of a few degrees which is normally used to drive a pointer. This instrument can be simply adapted, for electrical transmission, by means of an added differential transformer linked to the output shaft. When fitted with its normal pointer indication as well, local indication is obtained independently of the electrical system. Other mechanical flowmeters can be adapted in a similar way to meet this requirement.

The basic arrangement shown in Fig. 23 applies to many other simple loops such as those for control of temperature level, etc.

6.2 Compensation of flow measurement

When gas flow rate is to be measured it is often necessary to compensate for pressure and temperature variations. This provides an interesting illustration of the computing techniques mentioned in Section 4.4. Over a reasonable range of variables, the mass flow of gas is given by $\sqrt{(P\Delta P/T)}$ where

P = gas pressure
ΔP = orifice differential pressure
T = absolute temperature of gas

Square root and pressure correction. In this example temperature is assumed to be constant. The arrangement used is shown in Fig. 24a. The output, from the pressure transmitter, is fed via an amplifier to energize the differential transformer in the differential pressure transmitter. This subsidiary amplifier has a precise gain of 230, obtained by the use of the feedback, and so provides a voltage from 0 to 115 V from a 0–0·5 V output of the pressure transmitter. As a result, the output of the differential pressure transmitter is proportional to $EP\Delta P$. This product is fed to a recorder or indicator adapted for finding a square root, as described in Section 4.4,

and the indication is the required quantity, independently of mains voltage variations. The output of differential transformer 1 in the square root unit is suitable for retransmission if required and the output of the subsidiary amplifier A2 can be fed to an integrating meter for flow totalizing.

Square root and pressure and temperature correction. The arrangement shown in Fig. 24a can be used for temperature correction if the differential transformer 1 in the square-root unit is fed from a temperature transmitter. The connexion is shown as a broken line. The output of differential transformer 2 is then proportional to $ET\theta$, so that in equilibrium,

$$EP\Delta P = ET\theta^2$$

whence

$$\theta = \sqrt{(P\Delta P/T)}$$

However, this arrangement requires three auxiliary amplifiers, and a simpler arrangement is possible, as shown in Fig. 24b. In this the ratio ET/P is formed by the computing circuit of the form given in Fig. 12a. The output from this energizes differential transformer 1 of the square-root unit, and the output from differential transformer 2 is $E(T/P)\theta^2$, so that in equilibrium

$$E\frac{T}{P}\theta^2 = E\Delta P \quad \text{and} \quad \theta = \sqrt{\left(\frac{P\Delta P}{T}\right)}$$

It is interesting to note here, that apart from the essential instruments, required for the measurements and for recording the final result, only two simple a.c. amplifiers are added to perform the calculation.

6.3 Ratio control

Occasionally it is required to control a process variable so that it is related to another variable by a constant ratio. This may arise, for example, in a liquid mixing problem, when one variable may be uncontrolled or controlled in some other part of the system. In ratio control this uncontrolled variable is measured and the resulting signal used as a set point for the controlled dependent flow. It is usual to require some means of adjustment of the ratio and accordingly an a.c. amplifier with stable gain is used between the uncontrolled measurement transmitter and the controller. This has a gain of 2 and is provided with an adjustable potential divider at its output. The set point of the controller flow can be set anywhere between 0 and 2 times the uncontrolled flow signal.

6.4 Cascade control

Where a process includes a number of distance-velocity or exponential lags, cascade control can often be used to improve the speed of response and to reduce the effects of disturbances. Both the primary and subsidiary controllers can be of the type described in Section 5. The set point of the subsidiary controller is provided by the output of the primary controller. Since this latter output is a d.c. signal a conversion to a.c. is required to provide a 0–0·5 V a.c. signal for the subsidiary controller. The cascade convertor, which performs this function, is a unit of the d.c./a.c. convertor shown in Fig. 8 (July, p 7). It is suitably shunted, for use with a 4 mA signal span, and biased to give zero output for 1 mA d.c. input. The convertor output signal is fed out via a cathode follower.

6.5 Boiler control

Instrument schemes for boiler control vary widely depending on the type of boiler and its purpose. A scheme suitable for a process steam boiler, with mixed gas and oil firing, is described as an illustration. Although this example is on fuel

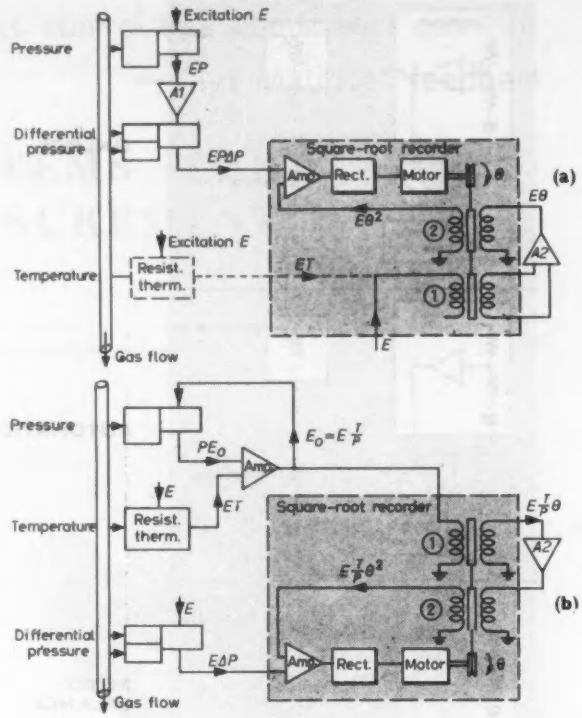

Fig. 24 Compensation of flow measurement

(a) Pressure compensation
In equilibrium $EP\Delta P = E\theta^2$
$\theta = \sqrt{(P\Delta P)}$

(b) Pressure and temperature compensation
In equilibrium $E\Delta P = E\frac{T}{P}\theta^2$
$\theta = \sqrt{\left(\frac{P\Delta P}{T}\right)}$

control only, it is intended as a typical one, and full boiler instrumentation can of course be carried out with units of the system.

In the example, steam pressure is maintained at a constant value, gas is burnt preferentially up to its maximum availability and oil is used to meet any demand exceeding this maximum rate. It is assumed that an a.c. signal in the range 0–0·5 V is provided to indicate the maximum rate at which gas can be burnt. This rate may be set manually or derived automatically at the gas generator.

The general arrangement of the scheme is shown in Fig. 25. Steam pressure is measured by a diaphragm-type transmitter whose output is fed to a controller with proportional-plus-integral terms. The d.c. output from the controller is converted to an a.c. signal with a cascade convertor unit (see Section 6.4).

Individual fuel rates are measured and linear signals derived with square-root-extraction recorders (see Section 6.1). The output of each square-root-extraction unit is suitably scaled, taking into account fuel calorific values, so that signals F and G represent the separate heat inputs to the boiler. The master controller output E_o is fed to the set-point inputs of the fuel controllers via subtraction units using transformers as described in Section 4.4.

The gas flow rate G is thus caused to follow the signal E_o–F i.e.

$$G = E_o - F, \text{ so that } E_o = G + F$$

Thus since the measured signals express heat inputs, E_o represents the boiler steam demand. In the event that this demand can be met by gas alone, i.e. E_o is less than G_m, then $E_o - G_m$ is a negative quantity. This results in the oil flow valve being shut down leaving only a bypass oil flow. When the demand for steam, and hence E_o, exceeds gas availability, $E_o - G_m$ becomes positive and oil flow is controlled to this value. Since the oil flow signal is subtracted from that fed to the gas controller the gas flow becomes

$$G = E_o - F = E_o - (E_o - G_m) = G_m$$

i.e. gas is consumed at the maximum rate G_m.

6.6 Heat output measurement

The computation of heat output from a boiler or heat exchanger involves the multiplication of temperature rise and coolant flow rate. This problem is of frequent occurrence, a notable recent example being the measurement of heat output from a nuclear reactor. A method for such a computation is shown in Fig. 26.

The temperature rise ΔT is measured with thermocouples at the inlet and outlet of the heat exchanger. The difference of the thermocouple e.m.f's is amplified and converted to a.c. by a thermocouple convertor. Flow rate is measured by a venturi and differential pressure transmitter. The differential pressure transmitter is energized by the ΔT signal via the auxiliary a.c. amplifier with a gain of 230. Thus the output from the differential pressure transmitter is $E\Delta PT$ and is fed to a square-root-extraction indicator whose differential transformer 1 is also energized by the amplified ΔT signal.

In equilibrium

$$E\Delta P\Delta T = E\Delta T\theta^2$$

and

$$\theta = \sqrt{(\Delta P)}$$

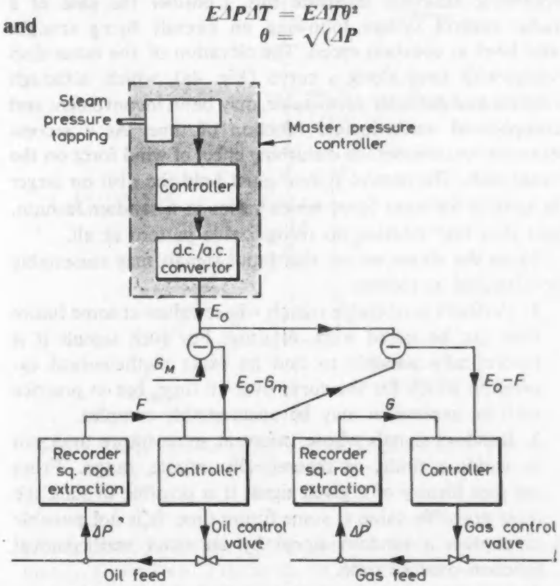

Fig. 25 How boiler fuel is controlled by the a.c. electronic system

The indicator thus shows flow on a linear scale. The output of differential transformer 1 is

$$E\Delta T\theta = E\Delta T\sqrt{(\Delta P)}$$

which is proportional to heat output and can be recorded on a standard recorder. The output from the auxiliary amplifier of the square-root-extraction indicator can be fed to an integrating meter to totalize the heat output.

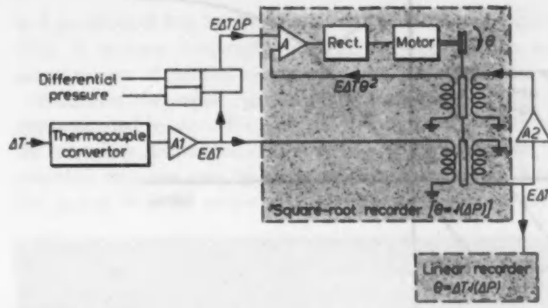

Fig. 26 Computing and recording the output from a heat exchanger

In equilibrium, $E\Delta T\Delta P = E\Delta T\theta^2$
Therefore $\theta = \sqrt{(\Delta P)}$
Input to linear recorder $= \Delta T\sqrt{(\Delta P)}$

6.7 Use with data-logging equipment

In data-logging equipment the inputs are scanned and presented in turn to a digitizer which may be either an electronic or a servo-driven mechanical device. Where a.c. input signals are used with electronic digitizers it is usually necessary to convert to d.c. Then a fixed-gain a.c. amplifier, followed by a phase-sensitive rectifier, provides a suitable solution. With mechanical digitizers, the normal reference slide-wire or potentiometer can be replaced by a differential transformer and the input signals balanced against its output. This avoids difficulties associated with the dependence of the a.c. inputs upon the mains voltage since these are compensated by similar variations in the feedback differential transformer. Where mixed a.c. and d.c. input signals are used it is not difficult to use a d.c. slide wire and a differential transformer driven by the same servo. A switch selects one or the other appropriately depending on the type of input signal.

7. Summary and conclusions

The use of electronic techniques for measurement, quality analysis, data logging and computing is increasing. In addition, with increasing complexity and size of plants, often in outdoor locations, the desire for centralized control leads to many difficulties when pneumatic equipment is used. Accordingly there is considerable interest in completely electronic control systems.

Of the possible forms of transmitted signal, amplitude modulation of a.c. or d.c. has been used to date for control equipment. The use of d.c. signals involves force-balance type transmitters which are more complex than the alternative displacement-type transmitters although difficulties are necessarily associated with d.c. measurement (e.g. thermocouples) when using an a.c. system. For the system described a.c. was chosen largely because of the simplicity of the transmitters.

A comprehensive system using measured signals that are a.c. transmitted has been described to illustrate the capabilities of electronic control. It is seen that all the functions of pneumatic systems are reproduced and that great flexibility is possible. Many extremely useful computations can be performed using the measured variables and frequently with very little equipment additional to that required for the basic measurements and recording.

Acknowledgments

The author is grateful to the Directors of Elliott Bros. (London) Ltd., for their permission to publish this article and to make use of data relevant to the electronic control system manufactured by them under licence from the Swartwout Company of Cleveland, USA. For permission to publish Figs. 4 (July) and 20 (August) thanks are due to the Fisher Governor Co Ltd, Rochester, Kent.

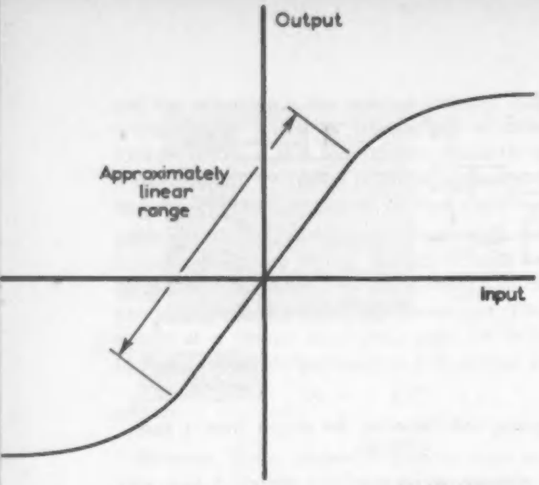

Fig. 1 A saturation characteristic

PART 3

by C. M. BURRELL, M.A., B.Sc., A.M.I.E.E.
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What is control engineering?

IN THE LAST ARTICLE certain properties (but not all) of linear feedback systems were demonstrated quantitatively. Before considering more general linear feedback systems it is convenient to mention various commonly occurring non-linearities, thus indicating the limitations of linear theory. In addition, we shall briefly explore various types of input signal in relation to their convenience in mathematical analysis, experimental measurement, and similarity to signals which actually occur in practice.

Non-linearities

No physical system is completely linear, and linear theory is used as an approximation (often very nearly correct) because of the extreme complexity of non-linear theory in all but very simple cases.

Saturation (Fig. 1) has already been mentioned as one form of non-linearity, and the limiting case of large gain and saturation giving an effective on-off action has been discussed. Most practical on-off systems possess some hysteresis, e.g. the thermostat actually switches off at a higher temperature than that at which it switches on. This characteristic is indicated in Fig. 2 and although, as we shall see later in this series of articles, an adaptation of linear theory can give a useful insight into the behaviour of on-off systems, it is obvious that straightforward linear theory is inapplicable.

On-off and saturation characteristics are similar in that they both occur at maximum control action. On the other hand, backlash, which often occurs in mechanical systems, is significant only for small signals or deviations even though its characteristic, when plotted on an appropriate scale (Fig. 2), is very similar to that of the on-off system. Linear theory is consequently useful for large signals compared with the backlash, but becomes ineffective when the signal is of the same order as the backlash. Thus in a device having saturation for large signals and backlash for small signals, there will usually exist a range intermediate between backlash and saturation, for which linear theory gives usefully accurate results.

Some other non-linearities which occur, apart from combinations of those already mentioned, are: coulomb friction (or stiction) which causes the frictional forces to be higher at low speeds and zero speed than would be obtained by a linear relationship to speed (as is the case when the friction is viscous) (Fig. 3); iron hysteresis, e.g. in the controlled field of a split-field motor (Fig. 3), and limit switches or stops built into a system to prevent self-destruction.

Although non-linearity usually complicates analysis, and there is therefore a strong temptation to build systems to which linear theory applies, it should be borne in mind that not only are vast numbers of essentially non-linear systems already in use, but that it is often possible to obtain improved performance by deliberately incorporating a non-linearity in an otherwise linear system.

Input signals

Precise mathematical representation of practical input signals is often difficult, and sometimes impossible. The following examples illustrate this. Consider the case of a radar control system following an aircraft flying straight and level at constant speed. The elevation of the radar dish varies with time along a curve (Fig. 4a), which, although smooth and perfectly predictable, may be an inconvenient and complicated mathematical function of time. As a second example we consider the disturbing effect of wind force on the radar dish. The control system must hold the dish on target in spite of the wind force which varies in a random fashion, and thus may contain no recognizable pattern at all.

From the above we see that input signals may reasonably be classified as follows:

1. Perfectly predictable signals whose values at some future time can be stated with certainty. For such signals it is theoretically possible to find an exact mathematical expression which fits the curve over all time, but in practice such an expression may be unacceptably complex.
2. Random signals whose values at some future time can lie within a finite, or theoretically infinite, range. From the past history of a given signal it is possible to state the most probable value at some future time. It is not possible to express a random signal by an exact mathematical function over all time.

As with the radar control system it fairly frequently happens that design must be based on following a given signal as well as possible in spite of an interfering disturbance or noise, which in this case is the wind force. In other systems the desired output itself may be random. Further consideration of random signals is beyond the scope of this series of articles, but the subject has received considerable attention over the past few years and the interested reader is referred to the literature (*1, 2*).

Returning now to non-random signals, we have the problem of reducing the complexity of the mathematical statement of

the signal to manageable proportions. The curve of Fig. 4a can be approximated to any desired degree of accuracy by a series of straight lines. A crude approximation is shown in Fig. 4b and the differential (first derivative) of this approximation is shown in Fig. 4c; it is seen to be simply a series of steps, i.e. a set of constant values separated by very rapid transitions. Now consider the case of a system attempting to follow the signal shown in Fig. 4c. For simplicity we will suppose that each constant value is sufficiently long for the system to settle to an almost steady value before the signal changes again. The system response will be somewhat as shown in Fig. 4d. Provided the system is linear each oscillation in Fig. 4d will be exactly the same shape, and once the response, to say a unit step, has been calculated, the response to the series is found by simply adding together a number of step responses of appropriate magnitude and time of occurrence. The response of the same system to the signal of Fig. 4b may then be obtained by simple integration of Fig. 4d.*

The response of a linear system to a single step is particularly easy to calculate, because the step consists of two steady states separated by a transition so rapid that the system output does not change during the transition. Details of the calculation will appear later in this article, when we consider the performance of a position control system. The idea of two steady states separated by a rapid transition can be carried further than this, and it is mathematically convenient to begin with what is known as a unit impulse. In its practical form this is a high-intensity, short-duration

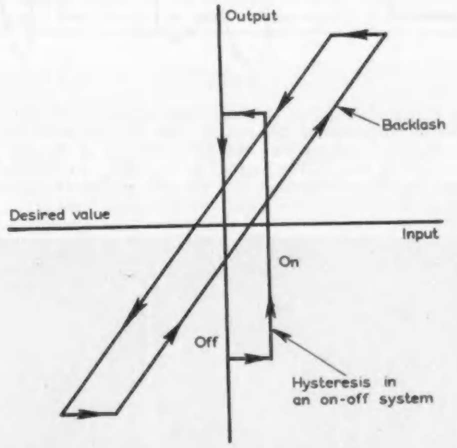


Fig. 2 These two non-linearities are often found in practical systems

signal, defined in such a way that its integral is approximately a unit step. Fig. 5a shows an impulse whose width and amplitude are defined such that

$$\int_{-\infty}^{\infty} u_T(t)dt = 1$$

As $T \longrightarrow 0$ the integral of this function becomes the unit step shown in Fig. 5b.

Repeated integrations give the unit ramp (Fig. 5c) and the unit parabola of Fig. 5d. This family of discontinuity functions (Fig. 5) is very frequently used in the specification and measurement of control system response.

Whenever the input signal can be sufficiently accurately approximated by discontinuities sufficiently far apart, so that the 'complete settling' condition of Fig. 4d obtains, then the complete response may be found as already indicated. When this is not the case, recourse can be had to the convolution

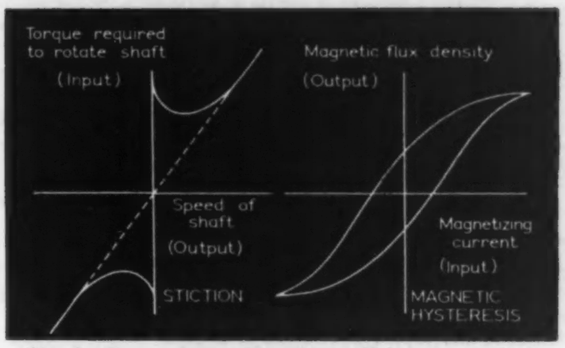


Fig. 3 Two more non-linearities which can complicate mathematical analysis

integral which may be considered as the limiting case of approximating the input signal by a very large number of steps or impulses (see Appendix 3 and Reference 3).

Transient analysis of a position-control system

The system to be analysed is shown schematically in Fig. 6 and is an electromechanical feedback system arranged so that the position of the output shaft follows closely that of the input shaft. Identical linear potentiometers fed from a common d.c. supply are attached to the two shafts, so that the difference between the two potentiometer output voltages is proportional to the misalignment of the input and output shafts. This difference, or error voltage, is applied to an amplifier whose push-pull output currents flow through the two field windings of a split-field d.c. motor. Zero error input to the amplifier produces equal currents in the two field windings and hence zero torque in the motor. Unequal field currents, produced by a non-zero error input to the amplifier, produces a motor torque of sign appropriate to reduce the misalignment of input and output shafts.

The remaining significant details of the system are as follows: the motor armature current I_a is held constant, whatever the speed, by a device which need not concern us; a gearbox is used between the motor and the output shaft; the motor field inductance is sufficiently small to have negligible effect for all rates of change of field current with which we shall be concerned.

The block diagram is shown in Fig. 7, from which it is clear that the system functions by controlling the energy supplied to the rotating parts so that the error voltage, and hence the shaft misalignment, is minimized.

The symbols necessary for analysis are listed as follows:

θ_i, θ_o input and output shaft positions respectively, v_i, v_o input and output potentiometer voltages respectively, related to θ_i and θ_o by a constant K_1 so that

$$\theta_o = K_1 v_o \text{ and } \theta_i = K_1 v_i \qquad . . . (1)$$

* It is shown in Appendix 2 that the integra lof the response of a time invariant linear system to a given input is the same as its response to the integral of that input.

G = amplifier gain in amp/volt

i_f = effective field current = $i_1 - i_2$ in Fig. 6

= effective amplifier output current

thus $$i_f = G\,(v_i - v_o) \qquad \ldots \ (2)$$

K_2 = motor torque constant, lb-ft/amp

thus torque due to $i_f = K_2\, i_f$

J = effective moment of inertia of all rotating output parts, referred to the motor shaft, slug-ft^2 [1 slug $\equiv g$ pounds mass]

K_3 = ratio of gearbox

F = viscous friction constant of motor and load, lb-ft-sec (note that in this linear analysis we ignore stiction, backlash, amplifier saturation and motor-field hysteresis)

The equation of motion of the system is obtained by equating torques at the motor shaft; thus

$$T = K_2\, i_f = \frac{1}{K_3}\left(\frac{Jd^2\theta_o}{dt^2} + F\frac{d\theta_o}{dt}\right) \qquad \ldots \ (3)$$

but $$K_2\, i_f = G\,\frac{K_2}{K_1}\,(\theta_i - \theta_o)$$

so $$J\frac{d^2\theta_o}{dt^2} + F\frac{d\theta_o}{dt} + \frac{GK_2K_3}{K_1}\,\theta_o = \frac{K_2K_3G}{K_1}\,\theta_i \qquad \ldots \ (4)$$

For simplicity we put

$$\frac{GK_2K_3}{K_1} = K$$

giving

$$\frac{J}{K}\frac{d^2\theta_o}{dt^2} + \frac{F}{K}\frac{d\theta_o}{dt} + \theta_o = \theta_i \qquad \ldots \ (5)$$

Writing p for d/dt we have

$$\frac{Jp^2}{K}\,\theta_o + \frac{Fp}{K}\,\theta_o + \theta_o = \theta_i$$

The dependence diagram for the system is shown in Fig. 8.

Putting $\theta_i = 0$ we have the homogeneous equation

$$\frac{Jp^2}{K}\,\theta_o + \frac{Fp}{K}\,\theta_o + \theta_o = 0 \qquad \ldots \ (6)$$

whose solution, the complementary function, is of the form

$$Ae^{s_1t} + Be^{s_2t}$$

where s_1 and s_2 are the roots of

$$\frac{J}{K}\,p^2 + \frac{F}{K}\,p + 1 = 0 \qquad \ldots \ (7)$$

namely

$$\frac{-F \pm \sqrt{(F^2 - 4\,JK)}}{2J} \qquad \ldots \ (8)$$

Consider the response of the system, initially at rest, to a unit step of input θ_i

Then for

$$t \leqslant 0 \quad \theta_i = 0$$
$$t > 0 \quad \theta_i = 1$$

Prior to $t = 0$ the whole system is at rest and, from (5) $\theta_o = \theta_i = 0$. Likewise, a long time after the step the system is again at rest and $\theta_o = \theta_i = 1$.

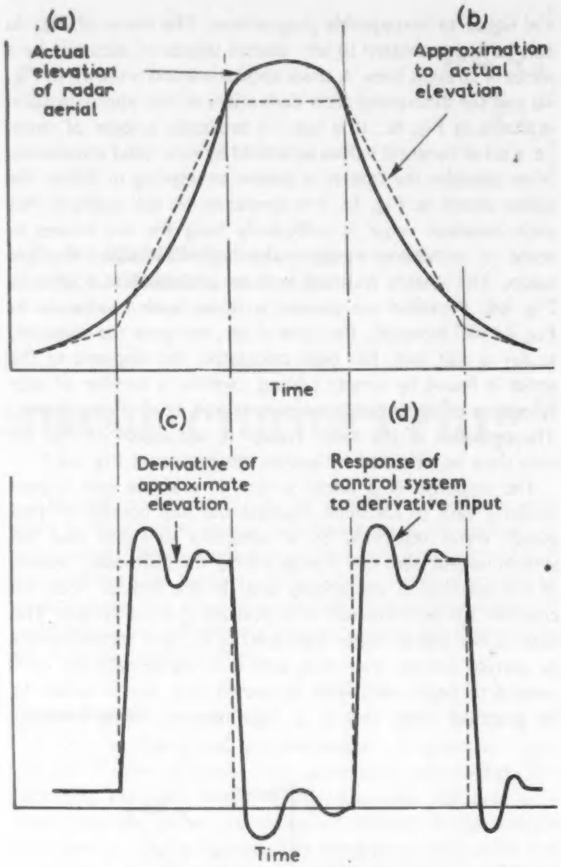


Fig. 4 The input (a) to a system can sometimes be approximately represented by straight lines (b). For analysing the system we assume that the derivative (c) of this approximation is fed to the system as an input; by integrating the response waveform (d) we can obtain the approximate response of the system to the actual input (a)

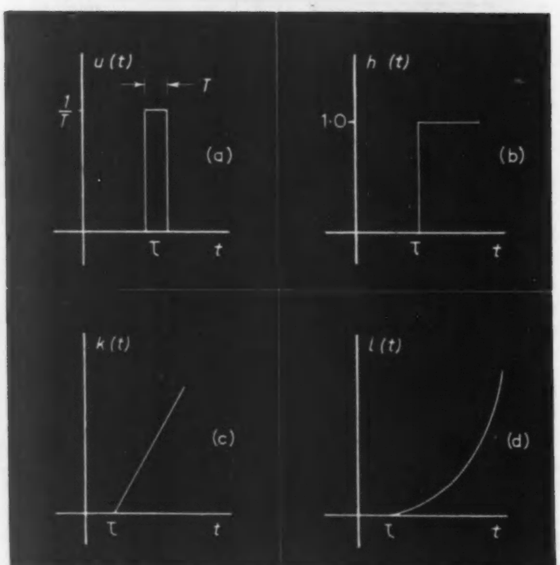


Fig. 5 These four discontinuities are used in the analysis and measurement of control system response: (a) impulse function; (b) unit step function; (c) unit ramp function; (d) unit parabolic function

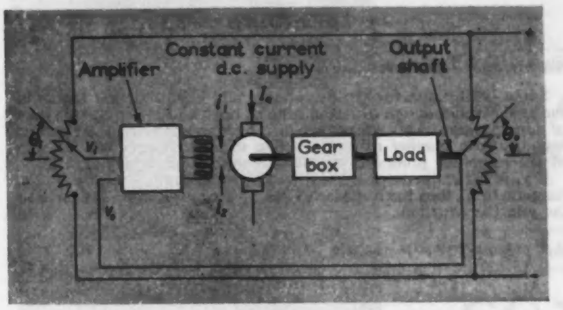


Fig. 6 A simple position control system. A rotation of the potentiometer on the left of the schematic will be followed by a rotation of the output shaft

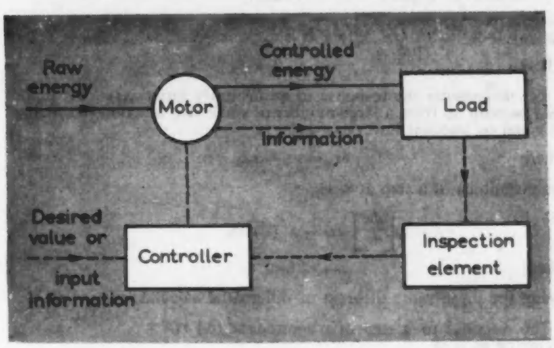


Fig. 7 The position control system functions by controlling the energy supply to the rotating parts so that the error voltage, and hence the shaft misalignment, is minimized

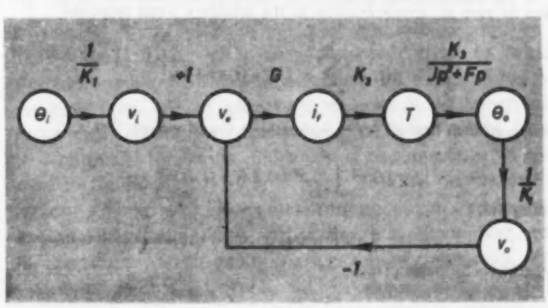


Fig. 8 The dependence diagram for the position control system

The complete solution to the equation of motion is thus

$$\theta_o = Ae^{s_1 t} + Be^{s_2 t} + 1 \qquad \ldots (9)$$

A and B remain to be found. Immediately following the step of θ_i, i.e. at $t = +0$, we can say that since the output acceleration is finite, both the output position and the output velocity must be zero.

Whence at $t = +0$ we have

$$A + B + 1 = 0 \qquad \ldots (10)$$

also

$$s_1 A + s_2 B = 0 \qquad \ldots (11)$$

(10) and (11) are quickly solved for A and B giving

$$A = \frac{s_2}{s_1 - s_2} \text{ and } B = \frac{s_1}{s_2 - s_1}$$

and the motion of the output shaft, following unit step of input θ_i, is given completely by

$$\theta_o = \frac{s_2}{s_1 - s_2} e^{s_1 t} + \frac{s_1}{s_2 - s_1} e^{s_2 t} + 1 \qquad \ldots (12)$$

The values of s_1 and s_2 determine the way in which θ_o changes from 0 to 1. Two characteristic cases arise, as may be seen from equation (8).

When $F^2 < 4JK$ then s_1 and s_2 are conjugate complex quantities, and the response is oscillatory. When $F^2 > 4JK$ both s_1 and s_2 are real negative quantities, and the response is monotonic. The two responses are illustrated in Fig. 9, together with the response when $F^2 = 4JK$, the condition known as critical damping.

Summary

Some examples of both practical and discontinuous inputs have been given. Certain discontinuity inputs (those consisting of two steady states separated by a discontinuity) yield relatively simple analytical solutions for the system response. Furthermore, a system response to any arbitrary input can be found in theory, and sometimes in practice, from the system response to one of these discontinuity inputs. Thus a linear system is completely characterized by its response to an input of this kind.

Some common non-linearities in electromechanical systems have been introduced and a simple electromechanical position control system (possessing most of these non-linear properties)

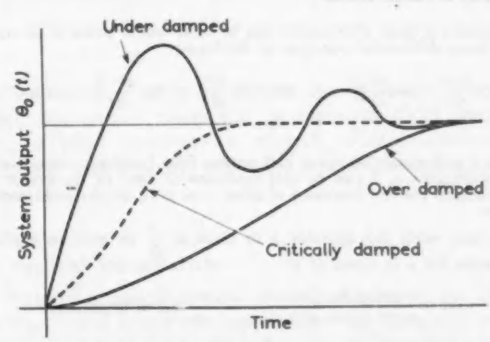


Fig. 9 The time taken for a system to settle down to a steady state will depend on its degree of damping

has been described and analysed using linear theory. Its step function response, given by the solution of a second-order linear differential equation, may be critically, under-, or overdamped (Fig. 9).

Experimentally, discontinuity inputs possess certain disadvantages, the most important of which is the fact that accurate comparison of input and output may be difficult due to the radical difference in shape of the two signals. The response of a linear system to a sine wave input is a sine wave of changed amplitude and phase. Furthermore, since any repetitive (although otherwise arbitrary) signal can be Fourier analysed into a number of sinusoidal components, it is possible by measuring the sine wave response of a system over a sufficiently wide range of frequencies, to obtain the response to many other signals. The steady-state sine wave response of linear systems, and in particular the position control system, will be dealt with in the next article.

APPENDIX 1

Mathematical definitions of certain discontinuous input signals

The unit impulse function (Dirac delta function)

$$u(t-\tau) = 0 \quad t > \tau \text{ or } t < \tau$$
$$= \infty \quad t = \tau$$

Such that

$$\int_{-\infty}^{\infty} u(t-\tau)\, dt = 1$$

or it may be defined as (Fig. 5a)

$$\underset{T \to 0}{\text{Limit}}\; u_T(t-\tau)$$

where

$$u_T(t-\tau) = \frac{1}{T} \quad \tau \leqslant t \leqslant \tau + T$$
$$= 0 \quad t > \tau + T \quad t < \tau$$

The unit step function (Fig. 5b)

$$h(t-\tau) = 0 \quad t < \tau$$
$$= 1 \quad t \geqslant \tau$$

The unit ramp function (Fig. 5c)

$$k(t-\tau) = 0 \quad t < \tau$$
$$= t - \tau \quad t \geqslant \tau$$

The unit parabolic function (Fig. 5d)

$$l(t-\tau) = 0 \quad t < \tau$$
$$= \frac{(t-\tau)^2}{2} \quad t \geqslant \tau$$

APPENDIX 2

Definition of a linear system

A system is linear if its output can be expressed in terms of its input by a linear differential equation of the form:

$$a_n \frac{d^n y}{dt^n} + a_{n-1} \frac{d^{n-1} y}{dt^{n-1}} + \ldots a_0 y = b_m \frac{d^m x}{dt^m} + b_{m-1} \frac{d^{m-1} x}{dt^{m-1}} + \ldots b_0 x \qquad (13)$$

where x and y are the input and output time functions respectively. The coefficients a, b can be real functions of time (if the system is time variant) but not functions of either x or y. In all physical systems $n \geqslant m$.

We may write the operator p in place of $\frac{d}{dt}$ to give an explicit expression for y in terms of x:

$$y(t) = \frac{b_m p^m + b_{m-1} p^{m-1} + \ldots b_0}{a_n p^n + a_{n-1} p^{n-1} + \ldots a_0}\, x(t) = W(p)[x(t)]$$

In order to justify the above algebraic treatment of the symbol p we must define $W(p)[x(t)]$ as a solution of the original differential equation. Thus $W(p)$ can be looked upon as an operator, which operates on $x(t)$ to give $y(t)$ which is a solution of the differential equation.

An integrator is a linear system since from its differential equation $\frac{dy}{dt} = x$ we see that the coefficients are constant and independent of x and y.

Putting p for $\frac{d}{dt}$ we get

$$y = \frac{1}{p} x$$

We see that $\frac{1}{p} x$ means the indefinite integration of x with respect to t (whilst px means the derivative of x with respect to t). Therefore p cancels out $1/p$ just as if p were an algebraic symbol. Similarly p^n cancels $1/p^n$.

By integrating both sides of the general differential equation of a linear time invariant system (13) and changing the order of differentiation and integration we see that

$$a_n p^n\left[\frac{1}{p} y\right] + a_{n-1} p^{n-1}\left[\frac{1}{p} y\right] + \ldots a_0\left[\frac{1}{p}\right] y$$
$$= b_m p^m\left[\frac{1}{p} x\right] + b_{m-1} p^{m-1}\left[\frac{1}{p} x\right] + \ldots b_0\left[\frac{1}{p}\right] x$$

Hence we may state that the integral of the response of a linear time invariant system to a given input is the same as its response to the integral of that input.

APPENDIX 3

Superposition—the convolution integral

Some justification for the use of step and delta function inputs in the analysis and design of linear systems can be found in the theorem of superposition. This states that in a linear system the total output response to a number of inputs acting together is equal to the sum of the responses produced by each separate input acting alone.

If y_1 is the response of a linear system to an input x_1 and y_2 is the response to x_2, then the response to $k_1x_1 + k_2x_2$ is given by the solution for y in the equation

$$a_n p^n y + a_{n-1} p^{n-1} y + \ldots a_0 y$$
$$= b_m p^m (k_1x_1 + k_2x_2) + b_{m-1} p^{m-1} (k_1x_1 + k_2x_2) + \ldots b_0 (k_1x_1 + k_2x_2)$$

$$= k_1 [b_m p^m x_1 + b_{m-1} p^{m-1} x_1 + \ldots b_0 x_1]$$
$$+ k_2 [b_m p^m x_2 + b_{m-1} p^{m-1} x_2 + \ldots b_0 x$$

$$= k_1 [a_n p^n y_1 + a_{n-1} p^{n-1} y_1 + \ldots a_0 y_1]$$
$$+ k_2 [a_n p^n y_2 + a_{n-1} p^{n-1} y_2 + \ldots a_0 y_2]$$

whence $\qquad y = k_1y_1 + k_2y_2$

Let us consider the response to an arbitrary input $x(t)$. This input may be built up from a large number of small step functions occurring at equal or unequal intervals $\delta\tau_r$

where $\qquad \delta\tau_r = \tau_r - \tau_{r-1}$

the magnitude of a step at τ_r is

$$t = \xi_r\left[\frac{dx}{dt}\right] \delta\tau_r = x'(\xi_r)\, \delta\tau_r$$

where $\qquad \tau_{r-1} \leqslant \xi_r \leqslant \tau_r$

(using the mean-value theorem of differential calculus)

The response to a step of magnitude $x'(\xi_r)\, \delta\tau_r$ occurring at τ_r is

$$v(t-\tau_r)\, x'(\xi_r)\, \delta\tau$$

where $v(t-\tau_r)$ is the unit step response occurring at $t = \tau_r$.

By the superposition theorem we may add the responses to all such steps to give an approximation to the arbitrary input response

$$y(t) = \sum_{r=1}^{n} x'(\xi_r)\, v(t-\tau_r)\, \delta\tau_r$$

As $n \to \infty$ such that all $\delta\tau_r \to 0$ then $\xi_r \to \tau_r$ and we get

$$y(t) = \int_{-\infty}^{t} x'(\tau)\, v(t-\tau)\, d\tau$$

noting that $\qquad v(t) = 0 \quad t < 0$

This integral is called the convolution integral.

Integration by parts gives

$$y(t) = \int_{-\infty}^{t} x(\tau)\, v'(t-\tau)\, d\tau$$

assuming $\qquad x(t) = 0 \quad t = -\infty$

and since $\qquad v(t) = 0 \quad t = 0$

but $\qquad v'(t-\tau) = w(t-\tau) \qquad$ (see Appendix 2

which is the system weighting function or delta function response and so

$$y(t) = \int_{-\infty}^{t} x(\tau)\, w(t-\tau)\, d\tau = \int_{0}^{t} x(\tau)\, w(t-\tau)\, d\tau$$

if $\qquad x(t) = 0 \quad t < 0$

Thus the system behaviour in response to any arbitrary input can be completely determined from the step or delta function response.

References

1 Newton, Gould and Kaiser: 'Analytical design of linear feedback controls' (Wiley, 1958)

2 Norbert Wiener: 'Extrapolation, interpolation and smoothing of stationary time series' (Wiley, 1949)

3 Gardner and Barnes: 'Transients in linear systems' (Vol. 1) (Wiley, 1942)

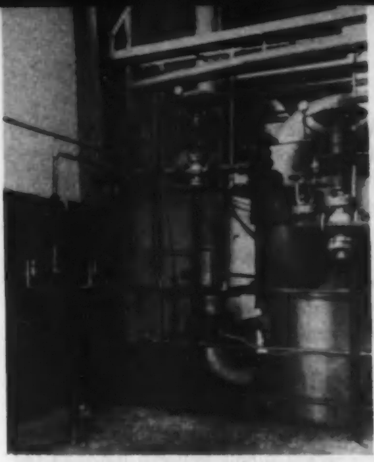


Fig. 1 Pressure transmitters and control valves on a chemical plant

Practical advice for the plant engineer inexperienced in electronic control gear

ELECTRONIC PROCESS CONTROL EQUIPMENT

installation and maintenance

by **R. J. REDDING, A.M.I.E.E.**

Instrumentation and Controls Division, Evershed & Vignoles Ltd

Elsewhere in this issue appears the concluding part of an article explaining how electronic process control operates and how it can be applied, by M. V. Needham, of Elliott Brothers. Here is an article which looks at electronic control equipment from a different viewpoint—that of fitting and maintaining it. Mr. Redding's opinion that preventive maintenance is not worth while with electronic equipment and that the golden rule is to leave well alone is especially interesting—and probably more controversial than the remainder of the article.

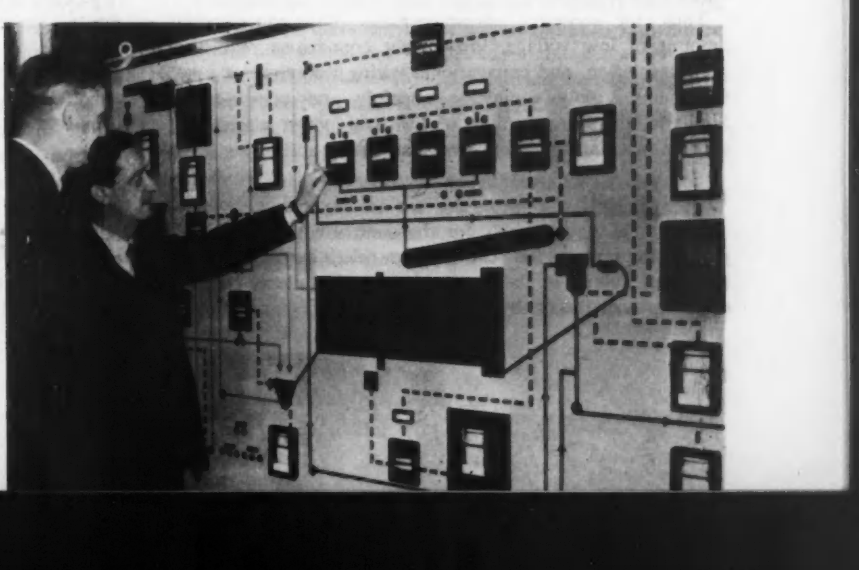
TODAY THERE ARE very few industries in which electronic equipment plays no part. In many industrial processes the use of electronic equipment has increased enormously in the last decade, and the trend seems likely to continue. Monitoring and analysis equipment previously used in the laboratory is now being installed on the manufacturing floor, and electronically operated process control equipment is finding fresh applications and taking over some of the duties traditionally performed by pneumatic and hydraulic systems.

Careful installation and attention to detail in cabling and power supplies will make or mar such equipment. In many installations standard wiring techniques and distribution as used for lighting and power circuits are quite unsuitable, as well as being far from economic. In this article I shall describe some of the pitfalls, and explain why special materials and techniques are often recommended by the manufacturers of electronic control equipment, to assist the plant engineer, who is often apprehensive of such recommendations by reason of their anomaly with normal heavy current industrial practice.

A typical installation

Parts of a typical process control installation are shown in Figs. 1 and 2, and the disposition of the apparatus will be much the same whether it is for a few supervisory instruments or a completely integrated control system. Electronic equipment gives considerable scope for positioning the various components; therefore, as a principle, items are centralized as far as possible in a control room rather than distributed throughout the plant. Fig. 1 shows measuring

Fig. 2 This graphic panel is used with an electronically controlled extraction process in a sugar refinery



devices and regulating units, which must of course be located at the appropriate points on the plant itself. The former measure the condition to be controlled and transmit an electric signal to the control room. A further signal generated by the control apparatus is fed back to position the regulating unit. The remainder of the equipment is located at the control point, and Fig. 2 shows a typical control panel, actually used for a sugar-refining process. From this panel the operator can observe the state of the process and override the automatic control when necessary. The electronic assemblies which generate the control and monitoring signals are arranged within the panel, but in large installations, a separate cubicle may be employed. Thus many cables are run between the control room and the various devices on the plant itself.

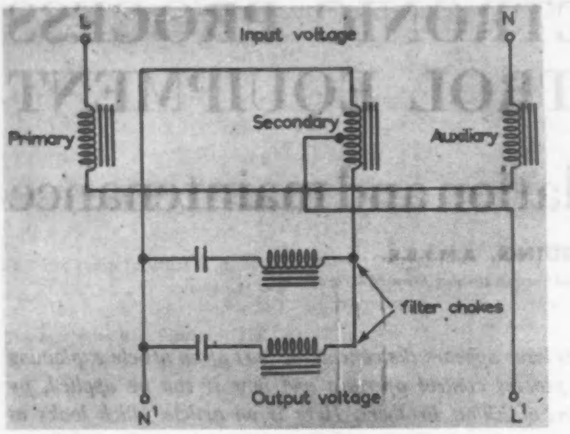


Fig. 3 Circuit diagram of a constant voltage transformer with harmonic filters

The signal level is usually quite small—a few milliamperes. At present there is no electrical equivalent to the pressure of 3–15 lb/in², which is standard for pneumatic equipment. Numerous electrical possibilities exist, but for the purposes of this article, I assume a direct current of 0–15 mA to be used. Normally such signals are independent of the circuit resistance over wide limits, and are unaffected by stray pick-up due to a.c. fields. However, each signal circuit should be isolated from all others (except where interconnexion is purposely made for complex control purposes) to avoid interaction due to leakages. This point is met by the use of isolating transformers between the power supply and the control signal circuits.

Thus, the complete system consists of a considerable amount of low voltage, low-current connexions requiring good insulation, and conventional wiring technique as used for mains supply would be ungainly and uneconomic. Similarly, the large number of low-level power circuits in such an installation require special switching and fusing.

Power supply

A suitable mains supply for the control equipment is of paramount importance. The first consideration is the continuity of supply in the event of a power failure. It may suffice to feed the control equipment from the same supply as the plant, provided that the control equipment is definitely not required if the plant cannot operate. On other occasions, safety requirements may demand a standby supply for lighting, to which the control equipment can be connected in an emergency. In some industrial surroundings it is possible to connect the control equipment to two separate sources of supply, e.g. two substations, both of which are unlikely to be out of action at the same time, with automatic changeover. The use of a d.c. supply presents difficulties due to the commoning of many circuits, unless a d.c./a.c. convertor is fitted.

I turn next to the stability of the supply voltage. It is usual to design electronic equipment to be independent of random changes in the power supply between limits of the order of $\pm$ 10 pc. However, in many industrial locations, considerable transient changes occur in the instantaneous value of the supply owing to intermittent loads and temporary overloads such as the direct-on-line starting of motors. Then the instantaneous value of the voltage may drop to a very low value. Electric motors and other industrial equipment for heating and lighting have considerable inertia, and the results of such transients are usually negligible. But electronic equipment is virtually instantaneous in operation, and violent changes are not without effect. In fast-operating equipment sudden depressions of the voltage would appear as an apparent cessation of supply. Under such conditions a constant-voltage transformer should be fitted as a surge inhibitor. In particular the response of the magnetic circuit is sufficiently fast—1 or 2 cycles of the supply—to mask the rapid changes which would otherwise cause a spurious response in most equipment. It should be noted that a voltage regulator using the step-change principle would aggravate rather than relieve the effect of a surge in the mains supply, by creating additional steep transients.

Usually a harmonic filter is necessary to provide a good waveform output, particularly where rectification is employed in the equipment. Fig. 3 shows the circuit diagram of transformers available for outputs from a few volt-amperes to several kilovolt-amperes.

It is of course possible to design electronic equipment to cater for very large variations in power supply, but this implies dissipating all the power above a certain level as heat. To operate with a drop of 30 pc in supply voltage means that half the input power at normal voltage would be wasted as heat, which is embarrassing and uneconomic: hence the two-stage approach to the problem. Where a constant-voltage transformer is necessary, a single unit can feed the entire instrument system, and the added cost of the transformer is well worth while.

Fuses and switching

Process control equipment consists of a large number of independent circuits, and it is desirable that each circuit, or at least small groups of them, should be individually switched and fused. A typical circuit has a consumption of the order of 15 VA, and hence an industrial 5 A fuse would provide rather inadequate protection. Moreover, the size of the electronic item is often commensurate with that of a commercial switch fuse, and were normal practice adopted it might result in a switch fuse board larger than the equipment concerned. Current practice is to fit individual fuses on each item, the connection of the unit to the supply being made by a plug and socket, enabling easy isolation for servicing and replacement. The sockets are connected to a

single mains switch fuse mounted within the panel. This means that power installation work on site merely consists of the connexion of a few mains supply leads.

Cables and terminations

The signal currents between the plant mounted equipment and the control panel are usually direct currents of the order of 15 mA, the actual current value representing some measured variable or the required corrective action. The voltage in the circuit seldom exceeds 30 V, but high insulation between wires and between individual circuits is essential, particularly where the connexions are made to thermionic valve circuits. Insulation in excess of 20 megohms is usually required, and this must be maintained over long periods in spite of the action of corrosive fumes and leaks in the plant-mounted equipment.

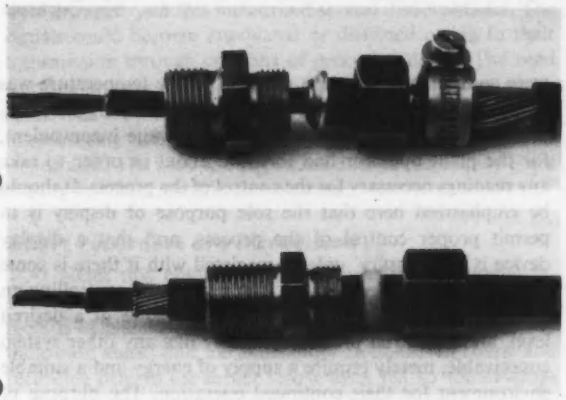


Fig. 4 Two designs of quick-release gland developed for use with telephone-type cable

From tests with cables of various materials, the best cable appears to be p.v.c. insulated telephone-type cable, and the colour coding which is inherent in such insulation is permanent and most advantageous. Such cable is far cheaper than the conventional lead-covered paper-insulated type, in which ingress of moisture may destroy the insulation.

A number of installations have been made by Evershed & Vignoles Ltd with complete success in vastly differing sites, using a cable specially developed for the purpose. This employs 9½ lb/mile tinned copper (0·024 in. dia.) covered with 0·020 in. of p.v.c. The smallest number of cores that can conveniently be made into a multicore cable is seven, and so this has been adopted as standard, even for applications where only two wires are required. The seven cores are sheathed in p.v.c., and may be armoured with galvanized iron wire. A final covering of fire-resistant braiding or a further p.v.c. or polythene sheath has been employed to prevent corrosion.

No special precautions are required in laying the cable. Light-gauge aluminium trays are often employed, and the cable may be directly buried in the ground without additional protection.

Special terminations are needed for the cable. Overhaul of the plant-mounted equipment usually means removal for workshop attention and calibration, and so one must be able to detach the cable from the instrument easily. For this purpose special glands (Fig. 4) have been evolved, and these enable easy disconnexion without disturbance to the armouring. Fig. 4 (a) shows the armouring made off to a short length of tube, which is then fixed to the unit with a pipe coupling. To remove the cable it is only necessary to disconnect the wires and to unscrew the gland nut which remains captive on the cable. A simpler gland, shown in Fig. 4 (b), uses a plastic compression joint fixed directly onto the p.v.c. sheath of the cable, the armouring being continued into the unit and not separately made off.

It is perhaps pertinent to stress a few subtle reasons why conventional technique should not be used. Were conduit wiring employed, the conduit would form a channel so that fumes and perhaps process fluids from a leak could enter the control room. Were metal-sheathed cable employed, stray currents between various points nominally at earth potential might arise, of sufficient magnitude to interact with the measurement signals, especially where thermocouples are employed for temperature measurement. Particularly is this so if cathodic protection is employed to reduce corrosion in the plant.

Servicing and maintenance

Servicing and maintenance recommendations may at first seem startlingly at variance with normal industrial practice. In particular, preventive maintenance is not generally applicable to electronic equipment. With few exceptions, electronic components have a long life, and their failure cannot be predicted with much certainty. Attempts at regular routine testing have been shown to cause more failures as a result of testing than would have occurred in the normal operation of the equipment. Testing and servicing represent a disturbance and some degree of overloading of the equipment, and the manufacturer's instructions on the frequency of attention should be strictly observed.

When tests are carried out, it is essential to make sure that a suitable test instrument is employed since, say in a high-resistance circuit, the resistance of the measuring instrument is very pertinent. For this reason, in more recent designs it has been customary to build in testing facilities within the equipment, so that the possibility of overloading the equipment or the use of wrong test gear cannot arise.

It is often recommended that electronic control equipment should be left switched on, say overnight when it is not in use. This perhaps does not seem strange when it is remembered that the heating and cooling which result from an intermittent supply can put a far greater strain on the equipment than would occur if it were left to idle. Similarly, switching off the equipment leads to cooling and the ingress of moisture and perhaps fumes.

The stocking of spares should be kept to a minimum, since the shelf life of some components is little, if any, longer than their working life.

Maintenance of electronic equipment is greatly simplified by the use of plug-in assemblies whereby a faulty unit can be removed and a fresh one substituted, so that actual servicing can take place in the workshop. However, the advantages of plug-in assemblies can be abused if substitution is made indiscriminately, and the golden rule should be: 'If it works, leave it alone'.

Reliability is a matter of design, installation and maintenance, and credit for the success of a particular control scheme lies as much with those on the site as with the manufacturer of the equipment.

Acknowledgment

The author thanks Evershed & Vignoles Ltd and Foster Transformers Ltd for cooperation and permission to use illustrations.

The Evolution of Plant Control

Force-balance pneumatics + data-logging electronics = plant control solution

by **O. G. PAMELY-EVANS, B.Sc., A.R.I.C.**
Sunvic Controls Ltd.

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IN THIS ARTICLE I am setting out briefly the history of industrial measurement and control in the process industries, and marking the points where divergencies of technique arose. The present position of pneumatic process control *vis-à-vis* electrical control is examined, and some predictions about its future are made. I am doing this with particular reference to the present Sunvic range of pneumatic control equipment, which, with its emphasis on force-balance methods, represents one—but not the only—outlook on modern pneumatic control.

Up to a few years ago the history of industrial plant* control was almost the same as the history of pneumatic control instruments. In the last few years electronic control systems have appeared and data-handling systems for monitoring of large plants have begun to be used in the process industries. There was a period in the late nineteen-thirties and early nineteen-forties when electrical plant control systems, not based on thermionic valve techniques, had a significant following, but their limitations, some of which persist today in their electronic successors, led to their decline in the face of the advance of pneumatic control systems.

Chemical and physical measurements

The two scientific disciplines most concerned with accurate measurement are physics and chemistry, and the measurement of industrial plant parameters is naturally an application of the basic principles of one or other of these sciences. It is interesting to note that the methods used by physicists involve displacement indicators, that is, parameters are converted into movements of a pointer across a scale. Chemical measurement, however, is based on the chemical balance, which is a force-balance method. The Wheatstone bridge is an example of a position-balance measuring device and is one of the more precise tools of the physicist.

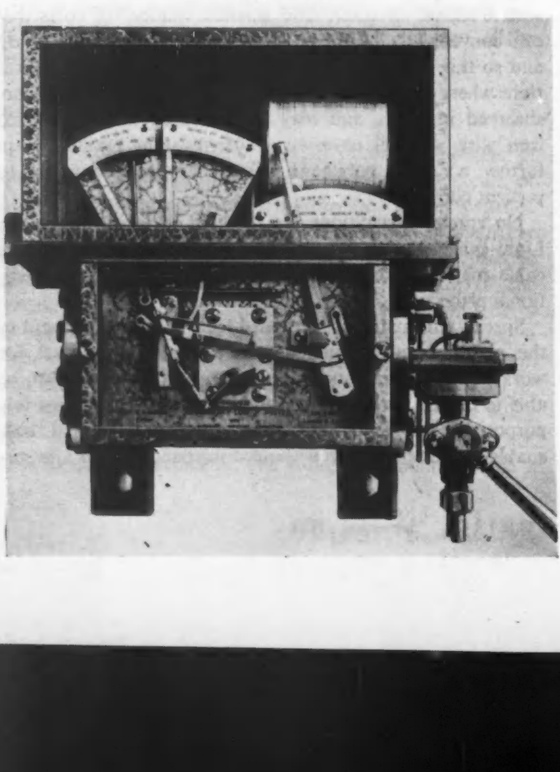
The purpose of display instruments

The earlier industrial instruments were simply displacement-type display units. Typical examples are pressure gauges and mercury-in-glass thermometers. Such simple apparatus had to be applied to the plant at approximately the point where the measurement was required. Pressure gauges were attached to mains conveying fluid, whose pressure had to be measured, and thermometers had to be inserted in whatever vessels were conveying the process material whose temperature was required. As plants became more complex and larger in size, this simple application of instruments became inconvenient, for the plant operator had to move about in order to take any readings necessary for the control of the process. It should be emphasized here that the sole purpose of display is to permit proper control of the process, and that a display device is unnecessary unless associated with it there is some manual method of regulation. The purpose of controlling an industrial process is to ensure its continuance at a desired level, and industrial processes, exactly like any other system conceivable, merely require a supply of energy and a suitable environment for their continued operation. The purpose of control, whether manual or otherwise, is to ensure that the environment of the process remains such that the process may continue, and the usual means of regulating the environment is to control the supply of energy. In simple terms, it is necessary to see that temperatures and pressures, flows and levels, remain within certain bounds in order that the process may be conducted satisfactorily.

Depending on human judgment

The early means of achieving this end were the display of simple parameters in a form easily apprehended by a human operator and reliance on him to take action necessary to maintain the environment of the process at its best level.

Fig. 1 An early form of indicator/recorder for temperature and pressure



* The expression 'process control' is in common use. I believe that this description could better be reserved for systems which actually control a process, and not just the physical environment of the process. Plant control may be defined as control of physical conditions—temperature, pressure, flow, level, etc—in which the process occurs. Process control implies measurement of process parameters, probably chemical, and is a development of the art approaching quality control, or the feedback of information from product analysis. This latter is tantamount to the concept of the 'automatic factory'.

It should be noted that the phrase 'best level' implies judgment on the part of the operator, a judgment dependent on the quantity and quality of information given to him by the display devices. In current terminology, the human operator is being used to 'close the loop'. An important function of the human operator is to be able to make reasoned forecasts on the data presented to him and based on previous experience of plant operation, but the implications of plant instrumentation were not fully understood in the early days, and, in fact, plant operation itself owes much to the development of process measurement and control techniques.

When it became necessary to group instruments so that the operator could perform his duties more efficiently, the type of instrument mentioned earlier was still used, so that process fluids had to be brought to wherever the instruments were grouped, and this introduced several disadvantages. The signals could become attenuated or distorted owing to their transmission through conduits of process material. The need to bring process material to the point at which the operator could read the instruments often led to hazard, as for instance in measuring temperature or flow of high-pressure steam or strong acid. The need to run process lines to the display point usually involved considerable expense.

Chart recorders are introduced

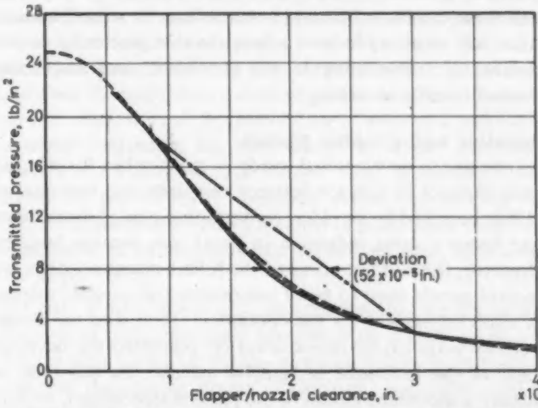
At about this point in the development of industrial instruments it became apparent that automatically produced records of plant variables would be of far greater value than indication alone, and the addition of clock-driven charts and recording pens to the earlier instruments led to the development of chart recorders (Fig. 1). These instruments were perforce bulky and complex, obtaining their timebase from a clockwork mechanism and their displacement by permitting mechanical forces to operate against a spring or balance weights through lever systems. The complete instruments were, therefore, prone to dead-spot and hysteresis, and subject to vibration. There was very little force left available at the position of balance, as one would expect from the design. Electrical signals were being handled by deflexion-type galvanometers with chopper printing mechanisms, until the advent of the self-balancing Wheatstone bridge, which used a power-driven servo. This latter type of instrument, although bulky and complex, has survived to the present day and is still in widespread use monitoring thermocouples, resistance thermometers, and strain gauges. The problems of transmission are less difficult with electrical signals than with others, which is one reason for the popularity of electrically-operated recorders.

Overcrowded control rooms

During the late nineteen-forties the increasing use of instrumentation, particularly in oil refineries, was beginning to overcrowd the panel on which the plant control instruments were mounted. Clearly the manning of control rooms would become increasingly difficult because of the large size of the unit instruments and the great extent of the display. Also, a great deal of complex piping and wiring had to be introduced into the control room to connect the instruments to the process which they were monitoring. Many of the recording and indicating instruments had by now automatic control devices incorporated into them, increasing their complexity and requiring that a signal from each controller should be led *out of* the control room back to the plant. A further difficulty arose because controllers developed for application to existing indicators and recorders required motion input; the whole instrument became, therefore, a delicate mechanical device with a complex arrangement of links, pivots, bearings, and rods. As long as these instruments were mounted in the control room in clean conditions, they operated well, but since plant signals had to be brought into the control room and control signals transmitted back to the plant, considerable time lags were introduced, and time lags in the control circuit are a main cause of instability in control systems.

A new approach brings new techniques

A revolution in techniques was obviously needed. It came some ten years ago when several changes took place in many new installations of plant control. First, plant parameters were measured close to the plant and converted immediately into pneumatic signals. This was done by using force-balance principles exactly like a chemical balance, with a great gain in accuracy and speed of response. Secondly, controllers were produced to accept both plant variable and desired value signals in the form of an air pressure and designed again to work on force-balance principles. A combination of the above two changes eliminated the need for conducting process fluids to the control room and controller signals back to the plant, since the comparatively small force-balance transmitter and force-balance controller could be located on the plant, with pipes which carried air in the pressure range 3–15 lb/in²



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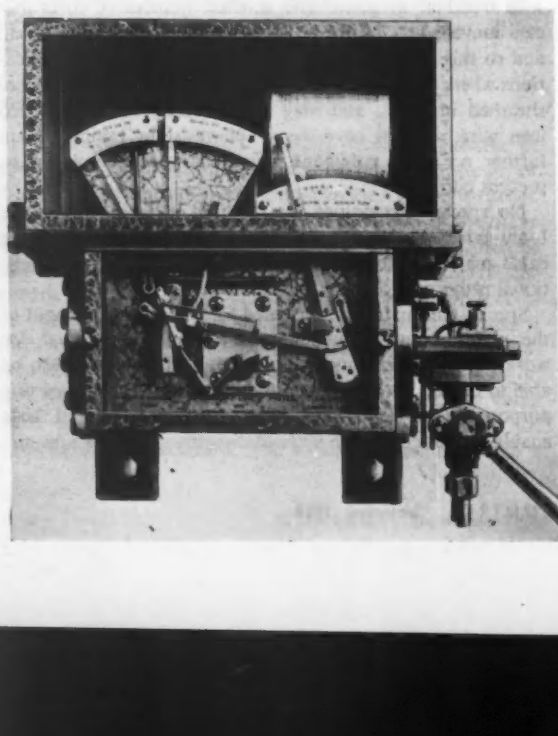

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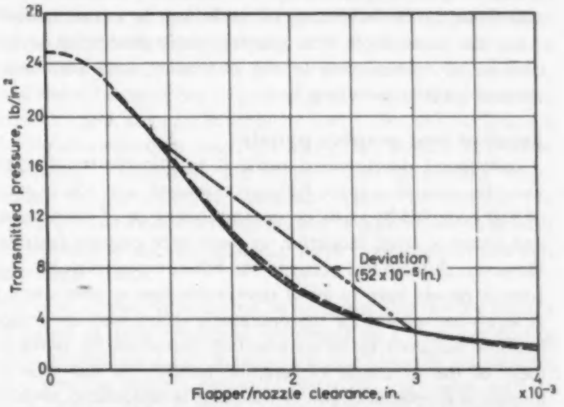

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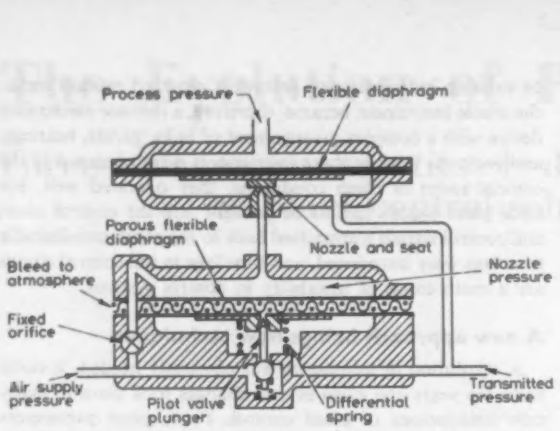


Fig. 3 An axially moving nozzle seat and a constant pressure across the nozzle are used to improve the performance of the pneumatic transmitter

have a third variable displayed—the controller output. It is also necessary to display the controller output in order to achieve 'bumpless' transfer of operation from automatic control to manual control—i.e. to bypass the controller, and to re-insert the controller in the control loop. Very often the controller output indicator is labelled 'valve position', but this makes an assumption that the part of the control loop between the controller and the actual control valve element inside the process line is operating and is characteristically linear. In general, displays of the three variables are required, and these can be indicating, or recording, or a combination. Also, it is necessary to have a desired-value generating device, capable of transmitting to the controller, and automatic/manual transfer switching.

Smaller and graphic panels

Instrument development made it practicable to offer all these features in a space between one-sixth and one-quarter of that occupied by an older, conventional type of instrument, and hence a great reduction in panel size became feasible. However, this did not occur to the fullest extent possible, for control panels have to be of reasonable size to offer display at levels convenient for the operator's vision, and the design freedom achieved by miniaturization permitted the development of the technique of 'graphic panels'. In this type of display, a simplified circuit of the plant is reproduced, usually in colour, with display instruments inserted at points in the mimic process lines corresponding to measurement or regulating units on the actual plant. The vogue for graphic panels is waning, although a much-simplified form may be retained for use with data-handling display devices.

Force-balance instruments

The basic mechanism around which many present-day pneumatic instruments are designed is a motion-detecting device, adapted to sense any unbalance between forces, exactly as the pointer on a chemical balance indicates the equality or inequality of masses in the scale pans. In most pneumatic force-balance instruments a flapper-nozzle system is used, in which an air pressure in a nozzle circuit is varied by the movement of the flapper. Such a device is sensitive, but very non-linear (Fig. 2).

In the most advanced form of such instruments (sometimes called 'unconventional') the pressure drop across the nozzle is controlled, and the crude flapper replaced by an axially-moving nozzle seat (Fig. 3). A great improvement in linearity is achieved (Fig. 4A), and a further stage of refinement, involving control of the rate of flow through the nozzle, produces quite remarkable linearity and great sensitivity (Fig. 4B).

If plant parameters are converted into forces, which are balanced against air pressures applied to diaphragms of very low spring rate, and the linearized nozzle system used to detect off-balance and initiate negative feedback, remarkably tough, yet sensitive measuring units can be designed such as those in the present Sunvic range. In the controller, a pneumatic pressure signal from the instrument is applied to one side of a diaphragm system, and an accurately generated

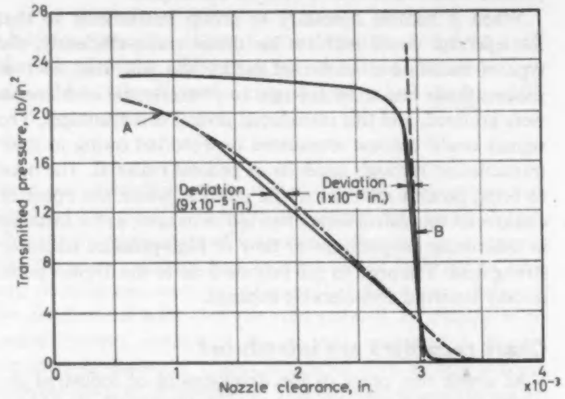


Fig. 4 Improved linearity is obtained by improved design
A. *For the transmitter of Fig. 3*
—— Experimental —.—. Desired linear relation
B. *For the transmitter of Fig. 3 with flow rate control added*
—— Experimental – – – – Theoretical

pressure, representing the desired value, to the other side; a linearized nozzle and a variable feedback circuit are incorporated. Such a controller is shown in Figs. 5 and 6. The unit is 'plugged in' to self-sealing sockets, and when removed leaves the controlled process 'locked'. An interesting illustration of the standards of performance achieved by such means is given in the published specification of the unit. It is sensitive to 0·01 pc change in signal, linear to 0·2 pc, will work immersed in 'dry ice', or in boiling water, and will suffer less than 1 pc shift in zero when subjected to 120*g* shock acceleration.

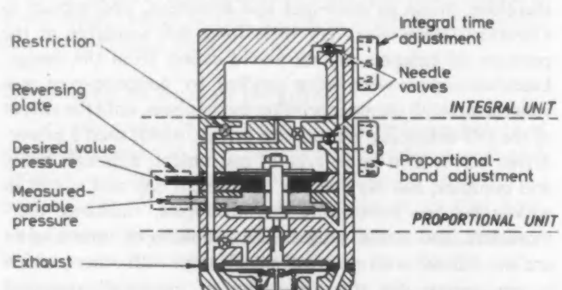


Fig. 5 This two-term pneumatic controller has virtually no moving parts. Preformed diaphragms give a low spring rate and withstand pressures up to 100 lb/in²

Desired value pressure   Measured variable pressure

With this type of equipment a coherent high-precision system of plant control can be achieved using basic physics simply applied.

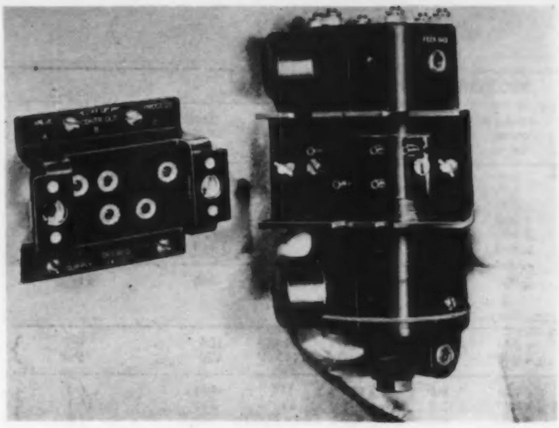


Fig. 6 The external appearance of the controller of Fig. 5, with the self-sealing manifold block into which it plugs and which can be mounted on the plant or in the control room

Similar force-balance techniques can be used to convert pneumatic signals to their electrical analogues, to take advantage of the superiority of electrical methods for telemetering, and for analogue/digital conversion (such as by a self-balancing servo and digitizing plate for printout methods of data-logging).

Pneumatic or electronic?

In plant control today two ends are being achieved by dissimilar and philosophically incompatible means. Measurement, control and limited (but vital) display is undertaken pneumatically. Pneumatic methods at present are basically in the analogue mode of data-handling. There is nothing wrong with this method—the truism that an analogue signal contains an infinite amount of information is still valid, and it is also true that the discrimination of a pneumatic analogue computer* is markedly better than that of a reasonable commercial display unit (e.g. a pressure gauge) which can accept the same signals. In other words, control errors will always be smaller than the plant operator can detect whilst control is maintained.

On the other hand, for scanning and digital display, it is required to have the signals in electrical form, so that very precise conversion from pneumatic to electrical analogue is necessary. Two ways of solving the dilemma are apparent—use of an all-pneumatic or an all-electronic system. The problems involved in the first alternative have not received much attention, but the advent of digital display has caused more interest to be shown in electronic methods of measurement and control. Tremendous problems confront the designer of an electronic control system—the basic thinking which led to the force-balance pneumatic system has to be almost completely reversed. The pneumatic system deliberately operates with large forces (approximately 50 lb thrust can exist in the pneumatic controllers described, during unbalance), and so swamps small spring-rates in materials of construction. Only minute forces are available electronically, unless large currents are envisaged, with their expensive conductors and great fire hazards. However, plant parameters usually exist as fairly high forces (pressures, flows, levels, etc) so that mechanical breaking-down of such forces must be employed. Two methods can be used—a system of levers (involving friction, backlash, wear, susceptibility to vibration, risk of high temperature coefficients, comparative fragility, and high expense of manufacture, adjustment, and maintenance) or absorption of the primary force on a spring, followed by measurement of the spring distortion (involving dependence on spring consistency which is affected by age, corrosive attack, and ambient temperature, and further dependence on mechanical displacement measurement). A combination of the two methods described could be used, involving a combination of the lists of potential errors—a truly alarming design problem.

* For example, a controller—the three-term pneumatic controller of the type described above is an analogue computer continuously solving a second-order differential equation with very high mechanical efficiency and power output.

Time-constants and control valves. When the plant parameter has been obtained in electrical analogue form it has to be digitized for display purposes, but is used still in analogue form for control computing. Here again great difficulties arise. Normal industrial plant time-constants are of the order of seconds and minutes—normal electronic time-constants are of the order of microseconds, and elaborate, expensive circuits have to be devised to generate the integral and derivative time-constants required—the constants which fall naturally in the range of those easily available pneumatically.

So far an electronic control system is an elaborate combination of the very mechanical features which have been studiously eliminated from modern pneumatic controllers, and intricate circuits devised to slow down electrical responses, but a worse difficulty follows. The final regulating element, the control valve, has to have an infinitely fine range of speeds (between limits), and to be capable of providing very high forces (thrusts of several tons are easily available pneumatically). Most electronic systems therefore have to use a pneumatic control valve as final element in the control loop, and since the major lag in control systems is in the pneumatic control valve, any gain in speed by use of electronic techniques is trivial—indeed, it has been shown by Boyd† that some electronic installations are slower than pneumatic ones, owing to the difficulty, outlined earlier, of making the electronic/pneumatic valve positioner (a position-servo device) as efficient as an all-pneumatic valve positioner, which can use larger forces.

The risk of fire. It will also be apparent that the fire hazard involved in using electronic equipment on a plant producing inflammable materials makes servicing virtually impossible, and that the delicate nature of electronic apparatus, and its susceptibility to ambient temperature change, moisture, vibration and dirt predispose designers to keep the instruments in the control room. The high speed of electrical transmission makes this feasible. It must not be thought that speeds of pneumatic apparatus are in any way in question industrially. A simple pressure regulator of extremely high precision, based on the linearized nozzle described earlier, has been oscillated full range at 8 c/s without perceptible signal attenuation or phase lag.

Conclusion

In general, it would appear that the pneumatic analogue methods of plant measurement and control will remain paramount for very many years, not only because they are well established already, but also because of their strength, accuracy, speed, extreme toughness (in the form described earlier), and very much lower capital cost.

Scanning and data presentation digitally will be electronic as far as can be seen, and the two systems will be integrated by interconversion units—not really a clumsy conception, for it enables industry to use the best technique in each field.

† *I.S.A.J.*, Nov. 1954, p 16.

A.C. MOTOR-GENERATORS

Manufacturer	Number	Description	MOTOR PERFORMANCE: Frequency/No. of phases	Ref. voltage, V	No-load speed, r.p.m.	Max. output power, W	Speed at max. power, r.p.m.	Control phase voltage, V	Stall torque, g–cm	Stall input power, W/phase
Evershed & Vignoles Ltd *Acton Lane Works, Chiswick, London, W4*	FV	induction	50 — 60/2	50	2 700	0·75	1 600	50	72	10 Ref 7·5 Con
			400/2	115	7 200	1·1	5 000	115	23·8	
	FAH	induction	50 — 60/2	50	2 800	1·8	1 600	50	173	11·5 Ref
	FD8	induction	50 — 60/2	50	2 700	2·8	1 600	50	274	12 Ref 9 Con
	FAF2	induction	50 — 60/2	50	2 800	5·0	1 600	50	430	16 Ref 13 Con
	FAE1	induction	50 — 60/2	50	2 900	16·0	1 600		1 610	39 Ref 36 Con
George Kent Ltd *Luton, Beds*		induction (with sealed lubrication, reduction gear 25 : 1)	50/2	110	2 000	0·78	2 000	180	146	11
Muirhead & Co Ltd *Beckenham, Kent*	F15C-10-B/1	size 15 induction	400/2	115	4 500	1·49	2 500	115SP	104	6·1
	F18C-10-D/1	size 18 induction	400/2	115	4 500	2·83	2 500	115SP	170	9·0
R. B. Pullin & Co Ltd *Phoenix Works, Great West Road, Brentford, Middlesex*	R800	size 15 induction	400/2	115	4 700	1·6	2 600	115	104	6·1
	R806	size 18 induction	400/2	115	9 000	5·0	4 500	115	202	16·1
	R807	size 10 induction	400/2	26	6 000	0·6	3 400	26 or 40CT	25·2	3·5
	R807G	size 10 induction	400/2	26	6 000	0·6	3 400	20CT	35	4·2
Sperry Gyroscope Co Ltd *Great West Road, Brentford, Middlesex*		size 11 induction	400/2	115	6 800	1·0	3 500	115CT or 20CT	45	3·45
		size 8 induction	400/2	26	5 000	0·2	2 500	40CT	12	
		induction	400/2	50	20 000	8·5	10 000	50	20	10
Vactric (Control Equipment) Ltd *196 Sloane Street, London, SW1*		size 11 induction	400/2	115	6 000	0·95	3 500	115SP	44	3·5

D.C. MOTOR-GENERATORS

Manufacturer	Number	Description	MOTOR PERFORMANCE: Armature voltage, V	Field current /voltage	Output power (max.), W	Speed at max. output, r.p.m.	Armature/field resistance, ohms	Stall torque, g–cm
Evershed & Vignoles Ltd *Acton Lane Works, Chiswick, London, W4*	FAA2	split field	220	0·80 mA field current	26	3 300	15/1 400	1 370
	FAG2				9	3 300	51/1 500	430
	FAD6				13	3 300	30/1 500	650
Newton Brothers (Derby) Ltd *Derby*	88X	'Velodyne' split field motor-generator	15	45 mA/55 V	12	4 000	2·5/1 300	180
	XC330		31·6	80 mA/100 V	16	900	8·6/1 275	1 200
	128		84	80 mA/100 V	16	900	256/1 275	1 200
	126		7·3	120 mA/142 V	16	900	0·4/1 275	1 900

D.C. SERVOMOTORS

Manufacturer	Number	Description	Armature voltage, V	Field current, A	No-load speed, r.p.m.	Output power (max.), W	Speed at max. output, r.p.m.	Armature/field resistance, ohms	Stall torque, g–cm	Moment of inertia, $g–cm^2$	Weight, g
Electromethods Ltd *Caxton Way, Stevenage, Herts*	900	permanent magnet	1·5	—	2 000	0·035	1 885	2·8/—	36	1·8	300
	901		6	—	2 000	0·097	1 845	40/—	40	1·8	300
	902		12	—	2 000	0·117	1 405	190/—	29	1·8	300
	903		24	—	2 000	0·145	1 260	700/—	30	1·8	300
	950		2·5	—	2 000			40/—	16·5	1·8	70
	951		5	—	2 000			190/—	12	1·8	70
	952		10	—	2 000			740/—	12·5	1·8	70
Evershed & Vignoles Ltd *Acton Lane Works, Chiswick, London, W4*	FA3A	split field	220	40-0-40 mA fields	6 400	26	3 200	15/1 400	1 370	284	2 380
	FB4 and FB6				7 000	42	3 500	8·2/1 700	2 160	375	3 400
	FB17 and FB16				8 000	65	3 900	8·2/1 700	2 800	375	4 650
	FB13 and FB12				9 200	100	4 500	8·2/1 700	3 960	375	4 650
	FP30				6 000	7	3 300	113/1 500	430	91	910
	FQ12				6 000	11	3 300	43/1 500	650	137	1 130
Laurence, Scott & Electromotors Ltd *Norwich*	size 11	permanent magnet	24	—	6 900	10·8	5 500	11/—	900		
	M4/1–1a	split field	220	80 mA in one coil, 0 mA in other (max.)	7 000	26·7	4 000	18/1350 (per coil)	1 260	329	2 160
R. B. Pullin & Co Ltd *Phoenix Works, Great West Road, Middlesex*	08P.M.	permanent magnet	28	—	8 300	3·6	5 000	37/—	170	3·4	45
	11P.M.		28	—	7 600	6·2	5 000	23·5/—	410	10·0	100
	15P.M.		28	—	6 700	12·9	5 000	6·1/—	800	31·0	180
	18P.M. 1		28	—	7 200	15·4	5 000	6·3/—	940	25	277
	B8	wound field	24	0·3 (continuous)		9·7	3 500	48/66	1 000	129	62
Vactric (Control Equipment) Ltd *196 Sloane Street, London, SW1*	P100	permanent magnet	28	—	9 000	5·2	6 400	16/—	200	20·5	130
	P200		6	—	10 500	1·55	7 500	2·7/—	50	4	50
	P800		6·3	—	6 000	6·6	5 100	0·24/—	600	10·5	160
	size 08		28	—	8 500	2·5	5 000	50/—	120	3	30
	size 11		28	—	8 000	6·1	5 000	16/—	300	5	102
	size 15		28	—	8 000	11·3	5 000	7·5/—	700	15	180
	size 18		28	—	7 500	16·5	5 000	/—	900	30	300

TACHOGENERATOR PERFORMANCE

Description	Voltage output, V/1000r.p.m.	Output impedance, ohms	Phase shift	Supply voltage frequency c/s	Moment of inertia, g–cm²	Weight, g
induction	0·6	820	25° lag	same as for motor	9·0	510
	0·8	—	—		9·1	510
	0·6				17·6	680
	0·8	430	20° lag		38·4	908
	0·8	430	20° lag		58·5	1 130
	0·8	430	20° lag		110	2 840
drag cup	0·14	175	50°	16/50	57 (referred to rotor shaft)	1 700
aluminium drag cup	3·1	2 200	5° (lag at 3 000 r.p.m.)	115/400	5·3	400
		2 200			5·7	540
drag cup	3·1	1 600	4·5° (lag at 5 000 r.p.m.)	115/400	5·26	400
	3·0	1 600	4° (lag at 5 000 r.p.m.)	115/400	5·73	570
	0·4	130	10° (max.)	26/400	0·88	130
	0·4	130		26/400	0·88	130
drag cup	0·5	600		115/400	1·3	175
	0·14	1 000		26/400	0·8	70
	0·16	300		8/400	7	140
induction	0·5	600	10° (max.)	115/400	1·3	200

CONTROL SURVEY 3

The second Control Survey *dealt with a.c. servomotors and in the third we show d.c. servomotors rated at less than 100 W, together with tachogenerators and motor-generators. The motor-generators are motors with a tachogenerator built in to form one unit. Many of the motors listed can be obtained with a wide variety of windings, and with additions such as reduction gearboxes and servo amplifiers.*

The following definitions have been used:

CT = centre tapped winding
SP = split winding

These conversions may be useful:

1 lb = 454 g
1 oz-in. = 72 g-cm
1 oz-in² = 183 g-cm²
Torque (g-cm) =

$$\frac{\text{Output power (watts)} \times 10^5}{1{\cdot}03 \times \text{Speed (r.p.m.)}}$$

TACHOGENERATOR PERFORMANCE

Description	Voltage output, V/1000 r.p.m.	Linearity	Output resistance, ohms	Generator voltage/current	Weight, g	Moment of inertia, g–cm²
permanent magnet	21	± 1 pc in load of 50 k ohm	180		3 060	340
					1 480	137
					1 700	183
separately excited	6·3	1 pc	230	24 V/14 mA	1 021	12
	30		475	80 V/	3 520	98
	30		475	80 V/40 mA	3 520	98
	28		475	24 V/150 mA	3 520	98

A.C. & D.C. TACHOGENERATORS

Manufacturer	Number	Description	Voltage output, V/1000 r.p.m.	Max. speed, r.p.m.	Torque required, g-cm	Armature resistance, ohms	Moment of inertia, g-cm.	Weight, g	Supply voltage and frequency	Input power, W
Electromethods Ltd *Stevenage, Herts*	924	d.c. permanent magnet	4·5	3 000	1 (starting)	800				
Evershed & Vignoles Ltd *Acton Lane Works, Chiswick, London, W4*	FFI/3	d.c. permanent magnet	17±2	8 000		55	88	909		
	FFIA/3		24±2	8 000		55				
	FFI/20		27±3	8 000		220				
	FFIA/20		39±4	8 000		220				
	FF1/6		45±5	8 000		550				
	FF1A/6		67±7	8 000		550				
	FA5/C5	d.c. separately excited, split field	0·5/mA	8 000	108 (at full ex-	220 (Field 400)	284	2 390	full excitation is 25 mA in 2700 ohm field, 62·5 mA in 400 ohm field	
	FA5/C13		0·85/mA	8 000	144 citation,	840 (Field 400)				
	FA5/B5		1·2/mA	8 000	108 3600r.p.m.	220 (Field 2 700)				
	FA5/B13		2·0/mA	8 000	144 and 10 000 ohm load)	840 (Field 2 700)				
Ketay Ltd *Eddes House, Eastern Avenue West, Romford, Essex*	105T2M	a.c. induction generator	1·0±2 pc	8 000			17·2	227	24 V 400 c/s	1·9
Muirhead & Co Ltd *Beckenham, Kent*	F15C15-A/1	a.c. drag-up motor	3·1			760	2·1	200	115 V 400 c/s	5·4
R. B. Pullin & Co Ltd *Phoenix Works, Great West Road, Middlesex*	08P.M.(T)	d.c. permanent magnet	2±10 pc	5 000	20 (at 5 000 r.p.m.)	35	3·4	45		
	18P.M.(T)	d.c. permanent magnet	10±0·1 pc	5 000	60 (at 5 000 r.p.m.)	150	25	277		
Sperry Gyroscope Co Ltd *Great West Road, Brentford, Middlesex*	Mk 1	d.c. permanent magnet	20	3 000	20 (starting)	300	95·6			
	Mk 2		5±0·5 pc	3 000	20 (starting)	20	95·6	425		
	Mk 3		16±1·0	3 000	20 (starting)	300	95·6	425		

The Director of BSIRA shows what detection really is —change in form of energy

ELECTRICAL TRANSDUCERS—1

Detecting Elements in Instruments

by **J. THOMSON,** M.A., D.Sc., F.Inst.P., M.I.E.E.
Director of the British Scientific Instrument Research Association

WHAT IS NECESSARY for automatic control of a 'process' —here taken in a wide sense as covering physical and chemical activity in industrial plant, machinery, vehicles, weapons, etc? One must (a) detect and measure changes in certain properties, such as position, temperature, pressure, humidity, which are characteristic of the process; (b) reduce the observed measurements of these properties to an appropriate scale; (c) possibly, relate them to one another; (d) feed back to the process a correcting signal or signals dependent upon the initial programming of the process and upon the reduced data obtained from the detectors.

It follows that methods of detecting and measuring changes in properties are of the greatest importance to the control engineer. Whatever his task may be, the first question he asks himself is how to detect and measure the variables which produce changes in the process. A device that gives a signal (preferably electrical) related in magnitude and sign to a change in a parameter such as temperature or pressure is called a *detecting element*, since its purpose is to inform the controller of the change. Detecting elements defined in this way can take very different forms. They have not been studied systematically nor have they been adequately classified. My object here is to bring to light their common features and to suggest a classification which may be useful to the engineer. Succeeding articles in this series will be concerned with individual detecting elements or with special classes.

Transducers

All detecting elements can be classified as *transducers*, although the converse is by no means true. A transducer is a device in which the primary action is to change one form of energy to another; in particular, control engineers are interested in transducers which transform to electrical energy, the subject of this series of articles. A good example of a transducer that is also a detecting element is the barium titanate ceramic which is extensively used to detect and measure vibration. The mechanical energy given to the barium titanate is partially transformed into electrical energy which can be amplified, measured and used to control a process. An example of a transducer which is not a detecting element is any form of engine—steam, internal combustion or nuclear. In an engine a particular form of energy is transformed into mechanical movement, but the transducer is not a detecting element. It is a prime mover.

It is difficult to classify every detecting element as a transducer, but nearly always the device involves an energy transformation overall. For example, a thermometer is in itself an instrument in which a small fraction of the total thermal energy is stored in a bulb and causes expansion of a liquid or gas. But when a thermometer is used for control purposes, leads must be taken through the glass to give an electric current. Fig. 1 is an excellent example of such an instrument, capable of controlling the temperature to one-hundredth of a degree by means of the twenty leads shown.

Forms of energy

A systematic classification of transducers as detecting elements would be of great value to the instrument designer, although such a classification would require continual revision to include new devices. From the point of view of the pure scientist such a classification would be based on the three apparently fundamental sources of energy. These are (a) *nuclear*, by which is meant the energy stored in the nucleus of an atom; (b) *atomic*, by which is meant the energy stored in the extra-nuclear or electronic part of the atom; and (c) *mechanical*, by which is meant the kinetic energy associated with a moving mass, whether the mass is large or small, but excluding any kinetic energy involved in (a) or (b) above. In basic terms transducer action can be described by means

	NUCLEAR	ATOMIC	MECHANICAL
NUCLEAR	—	Ionization	Nuclear pile
ATOMIC	Zeta	—	Internal combustion engine
MECHANICAL	Thermal fusion	Shock waves	—

TABLE I

of a table of three rows and three columns, all detectors falling into one of the six spaces shown in Table 1. In each square an example of a transducer or transducer action is given.

For the instrument engineer such a table is too general and has no engineering value. It is better to try to construct a table from the different forms of energy which are derived from these three basic sources. Unfortunately, there is some scope for individual choice in writing down the various forms of energy. But bearing in mind the object—to classify the

CONVERSION FROM →

CONVERSION TO → (rows)

TYPES OF ENERGY	NUCLEAR	ATOMIC	ELASTIC	HEAT	STATIC ELECTRO-MAGNETIC	RADIANT ELECTRO-MAGNETIC	MICRO-KINETIC	MACRO-KINETIC
NUCLEAR	—	Direct action is impossible	Direct action is impossible	Above 10^6 deg K	Not entirely impossible	Transformations by means of gamma rays	Transformations by means of particles	Impossible in laboratory
ATOMIC	Radioactive transformations (a by-product)	—	Direct action is impossible —	Thermal combination, dissociation and excitation Endothermic reaction	Stark and Zeeman effects Electric discharge	Photo-chemical reactions	Chemical change by particle bombardment	Detonation by impact
ELASTIC	No apparent direct action	Crystal formation	—	Crystal formation	Piezo-electricity Ferro-electricity Magneto-striction Loudspeaker	Modifications to molecular structure	Modifications to crystal structure	Generation of elastic oscillations
HEAT	No direct action, but final form	Exothermic reaction (excess)	Attenuation and super-sonic heating	—	Resistive losses	Absorption and degradation	Bombardment of matter in bulk	Friction and viscosity
STATIC ELECTRO-MAGNETIC	May occur but unknown	Volta effect	Piezo-electricity Ferro-electricity Magneto-striction Microphone	Peltier effect	—	Radio-frequency reception	Special high tension supplies	Dynamo, etc.
RADIANT ELECTRO-MAGNETIC	Gamma radiation	Chemical excitation of radiation	Feasible by means of the three effects above	Radiation from hot body	Radio-frequency emission	—	X-ray tube Alpha- or beta-ray transformation with gamma emission	Possible perhaps in future
MICRO-KINETIC	Alpha and beta particles Neutrons Mesons	Chemical ionization	An effect should be possible	Thermionic emission Molecular beam	Field emission Hall effect Particle accelerators	Photo emission Gamma-ray transformation with alpha and beta emission	—	Only via chemical action
MACRO-KINETIC	Final product in nuclear engine	Final product in i.c. engine	Spring motor or elastic motor	Steam engine	Electric motor	Radiation pressure effects	Practical applications feasible	—

TABLE 2

detecting elements—the instrument engineer may find Table 2 helpful; it will at least stimulate thought. Table 2 is much more detailed than Table 1, and this makes it possible to refine the classification considerably.

In explanation of the terms used, the following definitions may be adopted. By *nuclear* energy is meant that which *gives rise to* high speed particles or radiations that are themselves regarded either as *microkinetic* energy, i.e. the energy associated with fundamental particles by virtue of their masses and speeds, or as *radiant electromagnetic* energy with gamma rays. *Atomic* energy could almost be identified with *chemical* energy, for usually it implies stored energy associated with the outermost electronic shells. But it includes the energy stored in the inner shells which plays an important part in many detection actions. For example, characteristic X-rays are the *radiant electromagnetic* energy produced when the inner shells of an atom are restored to their stable states. *Static electromagnetic* energy is the energy found in electric circuits. It may take the form of electrostatic energy and be measured by $\frac{1}{2}CV^2$, or of magnetostatic energy and be measured by $\frac{1}{2}LI^2$. Such energy can be moved from one point to another by means of conductors, but it is still bound to the circuits. *Radiant electromagnetic* energy, on the other hand, is free to move in space and comprises the full electromagnetic spectrum from gamma rays to long radio waves. When there is interaction between this form of energy and matter, the absorption or emission is explicable in terms of photons of energy $h\nu$, where h is Planck's constant of action and ν is the frequency of the radiation. Although this is strictly true for all regions of the spectrum it is of engineering significance only for radiation of frequency greater than 10 000 Mc/s. Three other forms of energy mentioned in Table 2 are basically *mechanical*, but can be distinguished from one another by the nature of the effects they produce. *Heat* is a form of kinetic energy in which the atoms or molecules of the hot body move in a completely random manner. It is,

therefore, correct to describe heat as incoherent mechanical energy. The *elastic* energy stored in a substance is also a form of mechanical energy, but it is transformed into regular or coherent movements of the atoms or molecules giving rise to periodic changes in the material. Finally, *macrokinetic* energy is that due to congregations of atoms or molecules all moving with the same speed. This is the energy which is stored in a flywheel or generated by an engine.

Detecting elements

It is helpful to consider some examples of the universality of Table 2 in its application to detecting elements. First, let it be supposed that the control engineer wishes to measure the flow of liquid in a pipe. The simplest detecting element he can use is an orifice plate which produces a pressure difference between its upstream and downstream faces related to the rate of flow of the liquid through the orifice. The energy transformation which leads to detection and measurement is the storage of a fraction of the energy lost at the orifice as a head of liquid in a manometer—the transformation is from kinetic to potential energy within the macroscopic mechanical category. If it is desired to read off the differential pressure electrically (as is often the case) a second detecting element transforming from mechanical to electrical energy is necessary.

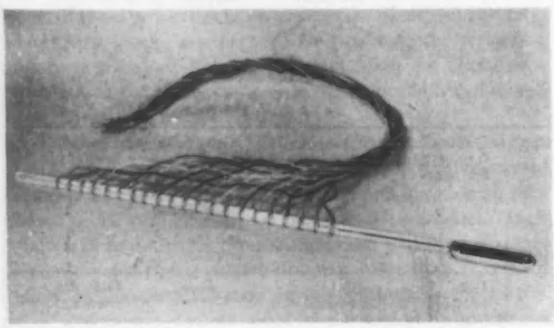


Fig. 1. A bridge circuit connected to the twenty leads of this electric-contact thermometer allows very accurate temperature measurement

This might be a device in which the resistance varies with the position of the levels in the manometer, or it might be piezoelectric, or it might even be photoelectric. An alternative method of measuring the flow to obtain directly an electric signal is to make use of the natural conductivity of the liquid and measure the transverse current in a magnetic field. Such electromagnetic flowmeters are in use today. The mechanical flow is imparted to the ions in the liquid, which are then caused to move at right angles to their path by the magnetic field. A third method which appears very promising is to use quartz crystals to generate and receive ultrasonic waves in the liquid. By timing these waves upstream and downstream the net flow of the liquid can be measured. This is a case of direct transformation from elastic to static electromagnetic energy in the detector and of the opposite in the generator. The flow energy plays an entirely insignificant role in the energy changes.

An example taken from an entirely different industry is the automatic measurement and control of the thickness of a sheet of some specified material. An instrument which might well be used in this case is the pneumatic micrometer in which a jet of air from a constant pressure source plays against the surface of the sheet. Changes in the distance between the surface of the sheet and the nozzle producing the jet are reflected in variations in the back pressure at the jet. This can be measured by a manometer with considerable sensitivity. The detection is wholly macrokinetic, involving a double transformation from potential to kinetic and back to potential energy. (There are exact electrical analogies in the behaviour of a transmission line terminated by a variable load.) If an electrical output is required, a subsidiary detecting element has to be used to transform from mechanical to electrical energy.

Another instrument which has the advantage that it need 'see' only one side of the sheet is the eddy-current gauge. In this case the balance between the two coils of a transformer

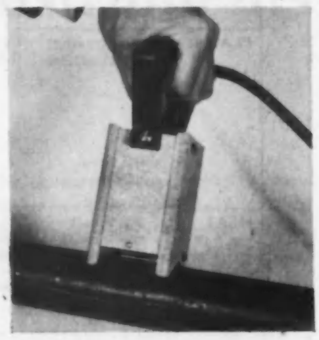


Fig. 2. An eddy-current gauge measures the thickness of the lead sheath on this cable

is upset by the propinquity of a sheet of metal, and under controlled conditions the thickness of the metal sheet can be estimated. Fig. 2 shows the head of a gauge which can be used to gauge the thickness of lead in cables. A more usual instrument for measuring changes in thickness is the beta-ray gauge. This comprises a source of beta rays on one side of the sheet and a counter on the other. Since the material is constant and variations in the absorption in the air-gap are negligible, the meter can be arranged to measure directly the thickness of the sheet. The detecting element is a transducer in which the transformation is from microkinetic to static electromagnetic energy, while the generator transforms nuclear energy into the useful microkinetic form.

Conclusion

It is hoped that enough has been said to indicate how the control engineer can widen his outlook on detecting elements by thinking in terms of energy transformations. No attempt has been made to discuss new or sophisticated detectors; but it may be worth noting that the advent of semiconductors as stable materials which can be made to a specification has widened the horizon enormously. In this field alone there are many examples of transducers turned detectors.

A logical classification of 'detecting elements' might well take the form of a chart in which the rows represent the various parameters to be measured and the columns the various output forms of energy. This would then lend itself to a simple reference system of the form $x.y$ or $xz.y$ or even $xwz.y$, where the integers before the point represented the family, species and variety of parameter and the integer after the point the output form of energy. This type of classification overcomes the difficulty that viscosity, length, dielectric constant, etc, are all important parameters, but are not in themselves forms of energy.

Acknowledgments

It is a pleasure to me to thank G. H. Zeal Ltd for permission to publish Fig. 1, and the Council of BSIRA for permission to reproduce Fig. 2. Table 2 was originally published in the *Journal of Scientific Instruments* and I am grateful to the Board of the Institute of Physics for permission to reproduce it.

ELECTRICAL DETECTION OF VARIABLES

by P. J. GEARY, B.SC. (ENG.) British Scientific Instrument Research Association

Automatic control or remote indication often begins with the electrical measurement of certain physical and chemical variables. Changes in the magnitude of a variable are converted into changes in an electrical signal by means of a detecting element or system which can be incorporated in, or otherwise arranged to influence, an electrical circuit. For a discussion of the fundamentals of detection see Dr Thomson's article elsewhere in this issue.

Detection can be regarded as taking place in stages within a detecting system. Sometimes there will be only one stage: thus variations in *temperature* will produce corresponding variations in the *electrical resistance* of a wire. In other cases detection is accomplished in two or more stages: for example, a change in *fluid pressure* will produce a *displacement* of the centre of a diaphragm which might in turn be arranged to produce a change in the *inductance* of an inductor; again, a change in *acceleration* will alter the inertia *force* acting on a suspended mass which may in turn be indicated by the *voltage* of a piezoelectric crystal.

The table lists some single-stage methods for the electrical detection of variations in some physical magnitudes. The column headings represent seven possible ways in which a detecting system may influence an electrical circuit for control or measurement. It is not claimed to be complete, and users of the data sheet may be able to fill some of the many gaps in it. Further development of detecting elements will almost certainly do this. It has been adapted, by permission, from a chart issued by the British Scientific Instrument Research Association as part of a research report. The full chart covers both single-stage and multi-stage detecting methods.

IN TERMS OF →	VOLTAGE OR ELECTRICAL ENERGY OUTPUT	FREQUENCY OF OSCILLATION	RESISTANCE	CAPACITANCE	INDUCTANCE	CURRENT OF EMITTED ELECTRONS	DIGITAL CODE PULSES	
DIFFERENCE OF LENGTH OR ANGLE LINEAR OR ANGULAR DISPLACEMENT STRAIN OR TWIST	Radius at which conductor is rotating in magnetic field Displacement of specimen showing Hall effect in magnetic field Displacement of gas discharge tube in magnetic field	Acoustic strain gauge	Moving contact resistors Resistance strain gauges Displacement of magnetoresistive element in magnetic field	Displacement of electrodes of capacitor	Displacement of part of inductor Synchros, etc	Displacement of part of thermionic valve	Digitizer Moiré fringes	1
LINEAR OR ANGULAR VELOCITY	Voltage across conductor moving in magnetic field (generator tachometer)	Frequency of passage of evenly spaced marks, notches, conductors, etc						2
FORCE WEIGHT PRESSURE OF CONTACT TORQUE	Piezoelectric crystal voltage	Piezoelectric crystal frequency	Carbon pile or granules		Magnetostrictive element.			3
HARDNESS					Magnetic measurement of hardness			4
THICKNESS OF SHEET MATERIAL OR A COATING DIAMETER OF A WIRE OR THREAD		Ultrasonic measurement of thickness.	Electrical resistance of a set length of strip or wire as a measure of the thickness or diameter	Material placed between electrodes of capacitor	Magnetic measurement of thickness			5
LIQUID LEVEL			Electrical resistance of vertical wire dipping into liquid.	Capacitance between liquid and vertical sheathed rod dipping into liquid. Electrode suspended over liquid Cylindrical electrode round wall of vertical tube	Liquid metal rises near inductor and alters its inductance			6
FLUID PRESSURE	Piezoelectric crystal voltage. Streaming potential of polar liquid	Piezoelectric crystal frequency	Electrical conductivity of an ionized gas (ionization pressure gauge)		Magnetostrictive element			7
FLUID FLOW RATE	Voltage across conducting liquid flowing through magnetic field (electromagnetic flowmeter)		Electrical conductivity across the flow of an ionized gas (ionization anemometer)					8
VISCOSITY		Piezoelectric crystal frequency						9
IONIZATION			Electrical conductivity of the fluid					10
PARTICLE RADIATION INTENSITY	Electrical energy from target							11
ELECTROMAGNETIC RADIATION INTENSITY OR FREQUENCY	Electrical energy from semiconductor junction Photovoltaic cell		Photoconductive cell Phototransistor	Phosphor infra-red detectors		Photoemissive cell		12
TEMPERATURE	Seebeck effect Nernst effect	Piezoelectric crystal frequency	Electrical resistance of wire or thermistor Transistor		Thermomagnetic materials			13
HUMIDITY OR WATER CONTENT	Voltaic hygrometer		Electrical conductivity of moist material. Electrical resistance hygrometer	Dielectric constant of moist material. Capacitance hygrometer				14
COMPOSITION OF MATERIALS PROPORTIONS OF MIXTURES	pH measurement Potentiometric titration	Sonic gas analysis	Electrical conductivity of the material. Polarography	Dielectric constant of the material	Magnetic measurement of carbon content of steel			15
DENSITY				Dielectric constant of the material				16
MAGNETIC FIELD	Hall effect		Magnetoresistive element					17
ELECTROSTATIC FIELD						Application of voltage to grid of thermionic valve		18

A velocity-modulated relay control system

by **JOHN C. WEST, PH.D., D.SC.**

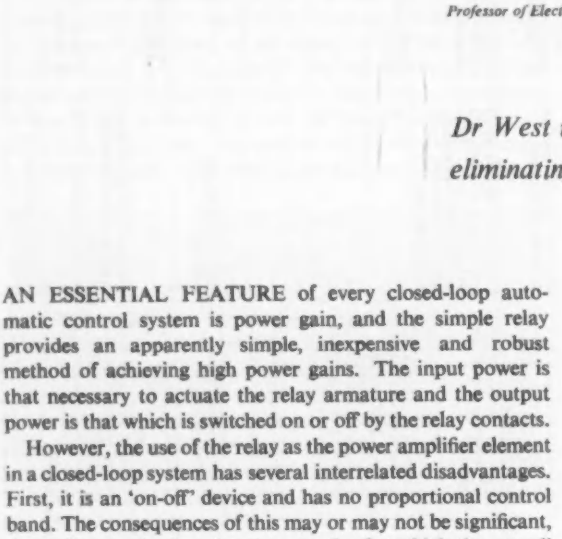
Professor of Electrical Engineering, Queen's University, Belfast

Dr West unfolds here for the first time a unique method of eliminating an undesirable feature of on-off control systems

AN ESSENTIAL FEATURE of every closed-loop automatic control system is power gain, and the simple relay provides an apparently simple, inexpensive and robust method of achieving high power gains. The input power is that necessary to actuate the relay armature and the output power is that which is switched on or off by the relay contacts.

However, the use of the relay as the power amplifier element in a closed-loop system has several interrelated disadvantages. First, it is an 'on-off' device and has no proportional control band. The consequences of this may or may not be significant, depending on the functional properties for which the overall system has been designed. In some systems it is sufficient to have an unidirectional drive such as in oven temperature control where the 'on' position of the relay causes heat to be supplied and the 'off' position stops the supply. Natural cooling provides any temperature reduction that may be required. In the majority of systems it is usually necessary to have control in both directions, as for the reversal of motion in position and speed control devices. The relay, for this, has three positions: one causes drive, two is an 'off' position and three causes drive in the reverse sense to one. An example will be taken, suppose that the relay element controls the torque of a servomotor in either direction with a small inactive or dead space region around the zero level of the control signal. Such a characteristic is shown in Fig. 1. If the system is free from output load disturbances then the maximum torque value T_M is determined from the requirements of system response time, since T_M is that torque which will be consumed in accelerating the servomotor and load. The system, however, may have to cope with varying load disturbances and for this T_M must be greater than the maximum load torque expected. This may give T_M a higher required value than from the previous consideration. The lack of a proportional control region is shown up when the system has a load torque in the steady state. No single position of the relay can satisfy the load condition (say T_L in Fig. 1). When turned on T_M is too great; when in the dead space the load torque T_L will move the system. It is found in practice that the system oscillates, spending a proportion of time in each period of oscillation with torque

Fig. 1 The characteristic of the relay element in a control system



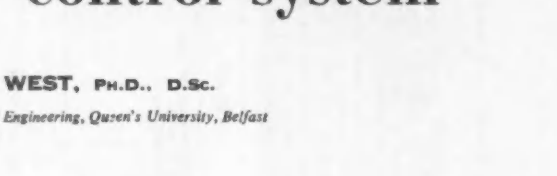


Fig. 2 Block schematic of a non-linear control system

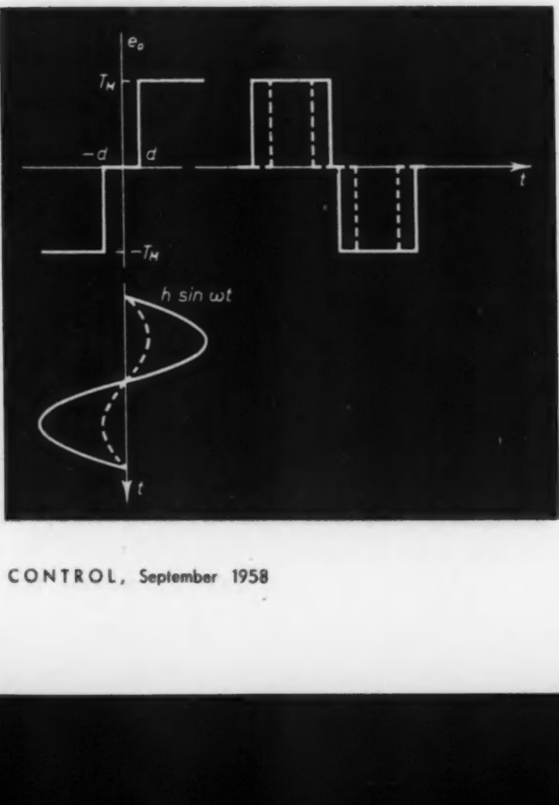
T_M, 0 and possibly $-T_M$. The system is self-regulating so that the average torque is equal to the load torque T_L. If it can be arranged that the oscillating frequency of the relay and torque variation is high, then because of the inertia of the load it is possible that the output movement is negligible and tolerable. This oscillation due to load disturbance is inherent in relay systems and can be eliminated only by introducing proportional control which involves costly linear power amplifiers. The period and amplitude of the oscillation is determined largely by the inertia of the load and the difference between maximum drive torque and the load torque $(T_M - T_L)$. The characteristics of the servo loop have only a secondary effect.

The second disadvantage of relay systems concerns accuracy and it is the overcoming of this disadvantage which is considered in this article. The final accuracy of the system will depend on the width of the inactive zone from $-d$ to $+d$ (Fig. 1). Since the control signal will contain the system error $\theta_i - \theta_o$, where θ_i is the system input or demand and θ_o is the system output or achievement, then errors in the steady state can be of the magnitude of $\pm d$. This means in practice that d must be small and the result, as will be shown in the analysis, is that invariably the system is continuously oscillatory and of a high frequency and low amplitude. This 'limit cycling' (*1, 2*) is tolerated in the interests of positional accuracy. It is more pernicious than the oscillations due to load disturbances because the latter cease when the disturbances are zero.

The third disadvantage is a very practical one and concerns contact wear. Relay systems have not become popular because of their short life, except in small power instrument-type servomechanisms. The life of a relay under fixed circuit conditions of load current and voltage is proportional to the number of switching operations, and the limit cycling which occurs in closed-loop systems is the main contributory factor to the resultant short life. It is appreciated that the contacts will have to be manipulated under transient conditions of error variation due to varying input demands or due to external disturbances, but in the total number of relay operations this is a small fraction of those produced by the continuous steady-state oscillation.

The aim of the work shown in this article was to eliminate the limit cycling phenomenon whilst retaining high accuracy

Fig. 3 Input-output waveforms of the non-linear element



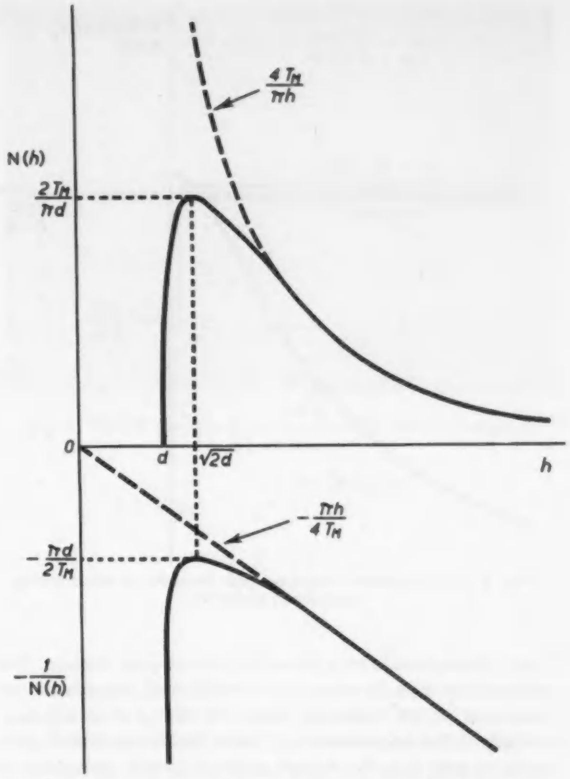


Fig. 4 The describing function for the relay element

(i.e. small value of d) in the steady state, and the philosophy underlying the approach was based on two facts:

1. The oscillation occurs with a period small compared with the response time of the system and it is only the effect on relay contact wear which is undesirable, not the oscillation itself.
2. The limit cycling is due in the majority of cases to the smallness of d and can be eliminated by having a large d (the system then has no accuracy worth mentioning).

An attempt has been made to make the dead space d a function of frequency instead of a fixed parameter. The width is kept small (theoretically zero) for frequencies in the working range of the system, thus ensuring high working accuracy, but increases with increasing frequency so that in the region at which limit cycling would normally take place the magnitude of d is sufficient to prevent the oscillations. The resulting method is not limited to electrical relays but applies to any form of power control having the type of characteristic of Fig. 1.

Limit cycles

The analysis of the performance of a control system with a non-linear element such as that portrayed in Fig. 1 is not, except in certain simple cases, amenable to rigorous and exact treatment. When conditions of continuous oscillations are being sought it is often possible, especially if the resulting oscillation is nearly sinusoidal, to make an approximation which enables the amplitude and frequency to be determined with reasonable accuracy. This method is referred to as the describing function technique (*3*) and virtually replaces the non-

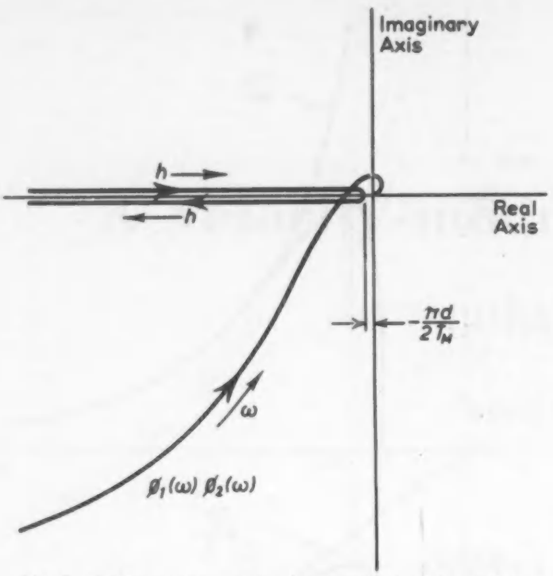


Fig. 5 The frequency response locus method of determining continuous oscillation

linear characteristic by a linear equivalent gain element. The value of the gain however is a variable and depends on the amplitude of the oscillatory signal at the input to the non-linearity. It has been shown (*4, 5*) that the best equivalent gain value to take (i.e. for minimum mean square distortion) is that value obtained by a Fourier analysis. If one supposes a signal

$$e_i = h \sin \omega t \qquad \ldots (1)$$

applied to the non-linearity with a characteristic

$$e_o \times f(e_i) \qquad \ldots (2)$$

then the true signal from this element will be a non-sinusoidal periodic wave given by

$$e_o \times f(h \sin \omega t) \qquad \ldots (3)$$

This can be expressed as a series such as

$$e_o \times a_1 \sin \omega t + a_3 \sin 3\omega t + \ldots a_n \sin n\omega t \qquad \ldots (4)$$

where all terms but the first are regarded as unwanted distortions. The first term is taken as the required portion of the output e_o and the equivalent gain k_e is a a_1/h.

It will be seen that a_1 itself is a function of h in the expansion of the series (4) from the function (3). This k_e is a function of the amplitude h and is written as N(h).

Consider a closed-loop control signal represented in a general manner as shown in Fig. 2 with linear frequency responsive elements $\varphi_1(\omega)$ and $\varphi_2(\omega)$ and a non-linear element. If a continuous oscillation is possible with zero input let this be considered to be approximately

$$e_i \times h \sin \omega t$$

at the input to the non-linear element. Then using the equivalent gain, the fundamental of the signal at the output from the non-linearity is

$$e_o \times N(h) \sin \omega t \qquad \ldots (5)$$

The function N(h) can be evaluated for any particular non-linearity, but the values of h and ω are still to be determined.

The output of the system is

$$\theta_o \times \varphi_2(\omega)\ N(h)\ h \sin \omega t$$

and hence by feedback round the loop (and since $\theta_i = 0$)

$$e_i = -\ \varphi_1(\omega)\ \varphi_2(\omega)\ N\ (h) \sin \omega t \qquad \ldots (6)$$

Comparing this with equation (1), we see that the condition for sustained oscillations is

$$N(h)\ \varphi_1(\omega)\ \varphi_2(\omega) = -\ 1 \qquad \ldots (7)$$

To investigate the possibility of such oscillations and to determine this amplitude and frequency when present, the simplest procedure is to plot $\varphi_1(\omega)\ \varphi_2(\omega)$ as a function of frequency ω, together with the function $-\ 1/N(h)$ as a function of amplitude h and obtain the points of intersection. If no intersection occurs then there is no possibility of this type of oscillation.

Without recourse to analysis the general form of the describing function for the relay element of Fig. 1 can be seen from Fig. 3. For a sinusoidal input with $h < d$ there will be no output, for h just greater than d the fundamental of the output waveform will be small but rising rapidly with increasing h. When h is large compared with d the output waveform is almost a square wave and the fundamental remains almost constant in magnitude irrespective of further increasing the value of the input h. Hence the gain which is the ratio of output to input magnitude eventually decreases inversely proportional to h. The complete function N(h) is shown in Fig. 4 together with the negative inverse $-\ 1/N(h)$. The expression for this function can be shown to be

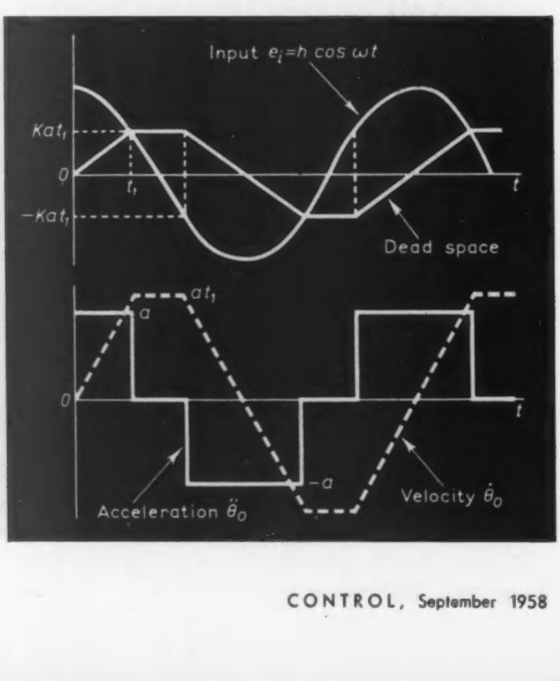
$$N(h) = \frac{4T_M}{\pi h}\sqrt{\left[1 - \left(\frac{d}{h}\right)^2\right]} \qquad \ldots (8)$$

for $h > d$.

The frequency response function of the linear portion of the system $\varphi_1(\omega)\ \varphi_2(\omega)$ is complex and must be drawn on a complex plane showing real and imaginary values of the function for each value of ω_1. Fig. 5 shows a typical response locus and superimposed on the negative real axis is drawn the inverse describing function of Fig. 4.

The intersections show the possibility of continuous oscillation. In practice it is found that the larger amplitude is the one that persists, the amplitude of the other being only metastable. It is also seen that if the dead space d of the non-linearity was increased sufficiently then the turning point of

Fig. 6 The various waveforms associated with the velocity-modulated non-linearity



the describing function in Fig. 5 would occur to the left of the frequency response locus and no intersection would occur. This explains the limit cycling which normally exists and how it can be eliminated if d is made sufficiently wide.

The frequency dependent non-linearity

In order to eliminate this limit cycling and still retain a small dead space d suppose that this width d can be made a function of the magnitude of the output velocity.

Let

$$d = K\,|\dot{\theta}_o| \qquad \ldots (9)$$

and consider the application of an input signal $e_i = h \cos \omega t$ at the instant $t = 0$. The relay will close and torque T_M will be used to accelerate the system. Let this acceleration be a and its value will depend on the moment of inertia of the motor and load. The velocity will be $\dot{\theta}_o = at$ and the width of the dead space will be increasing linearly with time as

$$d = Kat \qquad \ldots (10)$$

When this becomes equal to the input signal e_i then the relay will open and during the dead space the velocity will continue at constant magnitude (or falling magnitude if friction is considered). The relay will operate in the reverse direction when e_i is $-K\,|\dot{\theta}_o|$.

The process is cyclic and in Fig. 6 is shown the input sine wave, together with the variations of dead space, acceleration and velocity. The important feature is that the velocity wave form is exactly 90° lagging on the input wave form.

The describing function for the non-linear element will now be a function of ω as well as h, since the width d is velocity dependent. For analytical reasons it is preferable to obtain this gain function of the two variables from input e_i to output velocity $\dot{\theta}_o$ instead of to e_o as was done previously.

The width of the dead space at change-over at time t_1 is given by $Kat_1 = h \cos \omega t_1$. This is transcendental and t_1 cannot be obtained explicitly; however since the describing function method is approximate in the sense that harmonics are to be neglected it is possible to allow the sinusoidal wave form to approximate to a set of parabolae. Thus t_1 is given approximately by

$$Kat_1 = h\left(1 - \frac{\omega^2 t_1^2}{2}\right) \qquad \ldots (11)$$

The peak value of the velocity at_1 can then be determined as

$$[\dot{\theta}_o]_{\max} = at_1 = \frac{a}{\omega}\sqrt{\left[2 + \left(\frac{Ka}{h\omega}\right)^2\right]} - \left(\frac{Ka}{h\omega}\right)^2 \qquad \ldots (12)$$

The fundamental component of this waveform will depend on the relative time spent at maximum amplitude to the total period. It is however a variation from $4/\pi$ of the maximum value for a square wave, to $8/\pi^2$ for a triangular waveform, and for simplicity unit value is taken. This affects final accuracy but in practice the value of K would be determined by a final 'on test' adjustment, and it is the principle of the mechanism that is desired to be brought out and not exact magnitudes. Thus the output fundamental of the velocity will be taken from equation (12) as

$$\dot{\theta}_o = \left\{\frac{a}{\omega}\sqrt{\left[2 + \left(\frac{Ka}{h\omega}\right)^2\right]} - \left(\frac{Ka}{h\omega}\right)^2\right\} \sin \omega t \qquad \ldots (13)$$

Since the input is $h \cos \omega t$ the describing function can now be written in the form $N(h, \omega) = [\dot{\theta}_o]_{\max}/jh$

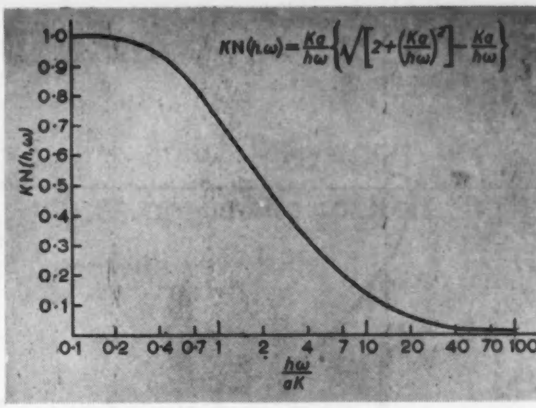


Fig. 7 The Z describing function for the velocity-modulated relay element

or

$$KN(h, \omega) = \frac{1}{jZ}\left[\sqrt{\left(2 + \frac{1}{Z^2}\right)} - \frac{1}{Z}\right]$$

$$= \frac{1}{jZ^2}\left[\sqrt{\left(1 + 2Z^2\right)} - 1\right]$$

where

$$\frac{1}{Z} = \frac{Ka}{h\omega} \qquad \ldots (14)$$

For large Z (i.e. large h or large ω or both) this function approximates to $\sqrt{2}/jZ$. The surprising feature is however that for small Z the function approaches a finite limit and does not become infinite for zero frequency or amplitude. Expansion of the square root for small Z shows the whole expression to become $1/j$ for $Z = 0$. This is shown in Fig. 7. The significance of the j factor is the shift of 90° from torque or acceleration wave form to velocity wave form.

Use of the Z describing function

The Z describing function depends only on the product of frequency and amplitude and not on either value independently. It is possible to use this function in much the same way as the frequency independent describing function previously discussed. In this case the non-linear block of Fig. 2 will contain the relay element and the transfer from acceleration to velocity. The block $\varphi_2(\omega)$ will be different from the previous case since it will now no longer contain the acceleration to velocity term $1/j\omega$.

i.e. when $\ddot{\theta}_o = a \cos \omega t$

$$\dot{\theta}_o = \frac{a}{j\omega} \cos \omega t = \frac{1}{j\omega}\ddot{\theta}_o$$

Thus $\varphi_1(\omega)\,\varphi_2(\omega)$ will be obtained from the previous locus of Fig. 5 by mutiplying by $j\omega$, i.e. by the magnitude ω and a phase shift of 90°.

The Z function will have to be plotted in negative reciprocal form to obtain the oscillating criterion, as in equation (7).

$$\varphi_1(\omega)\,\varphi_2(\omega) = -\frac{1}{N(Z)} \qquad \ldots (15)$$

If an intersection exists then the ω of the frequency locus is determined and also the value of Z. Since $Z = h\omega/Ka$ and ω is now known then h is also determined from the value of Z at the intersection. An example is shown in Fig. 8 and it is seen that oscillations (or intersections) are prevented by suitable choice of K. This factor K is a parameter of the system which

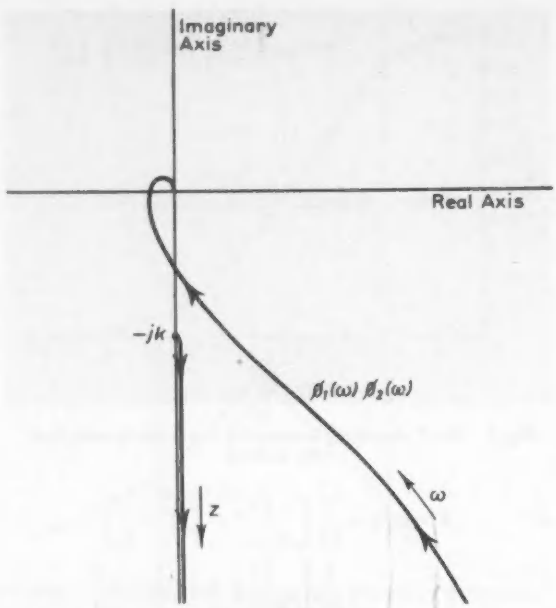


Fig. 8 The frequency response locus together with the function showing the absence of continuous oscillation

is under the designer's control and does not affect the final accuracy. The necessary value to eliminate limit cycling can always be achieved.

Conclusion

The previous section has shown how the use of a velocity-dependent dead space can be made to overcome limit cycling in relay control systems. The realization of such a non-linearity in practice is fairly simple in the case of a magnetic relay but may not be so simple for other types. It was for example a fairly complex electronic analogue circuit that had to be devised in order to study this phenomenon on a simulator. In the practical relay case d is determined by the critical value of magnetizing current required to move the relay armature. This can be made to hold off by providing a biasing winding in opposition with a current obtained from a tachogenerator proportional to velocity. The factor K is then dependent on the relationship of the coil current to the tachospeed. It was found that a relatively small value of K was sufficient to prevent limit cycling but that if K was increased by a large amount the system became overdamped and sluggish. Particular systems have not been described in detail as it has not yet been possible to analyse their performance for transient or statistical conditions. This is being undertaken. It is felt however that the principle of the use of velocity to modify a non-linearity and the development of a Z describing function in order to eliminate forms of oscillation, especially in relay systems, is of importance regardless of specific design parameters.

Summary

A method of eliminating the undesirable limit cycling of automatic relay control systems is described. This involves analytically a non-linear amplitude characteristic which is varied as a function of the system's output velocity. Sinusoidal analysis is employed and the treatment of this frequency- and amplitude-dependent function is obtained in a novel manner using a modified describing function.

References

1. Hammond, P. H.: 'The stabilization of on-off controlled servo-mechanisms. One paper of many contributed to a conference at Cranfield in 1951. The collected papers are published in book form: *Automatic and Manual Control*, edited A. Tustin. Butterworths Scientific Publications, London, 1952, pp 285–307
2. Weiss, H. K.: 'Analysis of relay servomechanisms' *J. Aero. Sci.*, 1946, **13**, p 364
3. Kochenberger, R. J.: 'A frequency response method for analysing and synthesizing contactor servomechanisms' *Trans. A.I.E.E.*, 1950, **69**, Part I, p 270
4. West, J. C. and Nikiforuk, P. N.: 'The describing function analysis of a non-linear servo-mechanism subjected to stochastic signals and noise' *Proc. I.E.E.*, 1957, **144**, Part C, p 193
5. West, J. C.: 'Modern trends in automatic control analysis'. Convention on Problems of Automation, Milan, 1956. Published by National Research Council of Italy, Rome, 1957

LOOKING AHEAD

A diary for the next three months

SEPT 22–29	*9th International Radio, Television and Electronics 'Firato' Exhibition* in Amsterdam. Details from Mr W. Friedhoff, 10 Gloucester Place, W1.
SEPT 24–26	*Instruments in the Electronic Age* Exhibition at Sheffield. The exhibition is organized by the Scientific Instrument Manufacturers' Association, 20 Queen Anne Street, W1.
SEPT 29–OCT 3	*British Electronic Component Show* in Stockholm. Details from Mr W. T. Ash, Radio and Electronic Component Manufacturers' Federation, 21 Tothill Street, SW1.
OCT 8	*Electronic Digital Computers*. The first in a series of one-day conferences with cooperation from various computer manufacturers will be held in Birmingham. Details from the Registrar, College of Technology, Gosta Green, Birmingham 4. Other conferences in the series will follow in December and the early part of next year.
OCT 13–15	*National Electronics Conference* in Chicago is sponsored by the Institute of Radio Engineers and other American professional organizations. Details from Mr J. S. Powers, National Electronics Conference, 84 East Randolph Street, Chicago 1, Illinois, USA.
OCT 13–18	*Congreso Internacional de Automatica*. See August p 61.
OCT 21–22	Two *Open Days* at the National Chemical Laboratory, Teddington. Applications not later than 20th September to the Director.
NOV 16–23	*International Conference on Scientific Information* in Washington. Details from the Secretary, International Conference on Scientific Information, NAS/NRC, 2101 Constitution Avenue, Washington 25, DC, USA.
NOV 24–27	*The Mechanization of Thought Processes*. A Symposium will be held at the National Physical Laboratory, Teddington, Middx. Details by telephone from Mr D. V. Blake at the laboratory (MOLesey 1380, ext 27).
NOV 28–DEC 4	*Electronic Computer Symposium and Exhibition*. Details from Mrs S. S. Elliott, 11-13 Dowgate Hill, EC4.

COURSES

SEPT 30–MAR 24 '59	*Instrumentation and Telemetering*. See August p 61.
OCT 8–MAR 18 '59	*Automatic Process Control*. See August p 61.

First British alkylation unit uses pneumatic controls —with few frills

New plant at BP's Kent refinery

DURING THE LAST TWO YEARS the British Petroleum Co has been extending its refinery on the Isle of Grain, Kent. A modern oil refinery consists of many units of plant handling different chemical processes, and under the expansion programme a dozen units, large and small, have been added to the Grain refinery. When the thermal reformer (for producing feedstocks for other units) goes on stream this month, one of the last of the additional units will be complete. Among the largest and most important additions is the alkylation unit, which went on stream in July this year. This unit is for producing light alkylate, a principal constituent of aviation spirit, and the output is about 86 000 gallons per stream day (some heavy alkylate for motor spirit is also produced). Recently a *Control in Action* reporter visited the Isle of Grain (no longer an island but a flat outpost of Kent), to see the alkylation unit and its instrumentation in operation. Some notes about the unit appear below; first we give a few additional particulars of the refinery in general.

Varying the product ratios

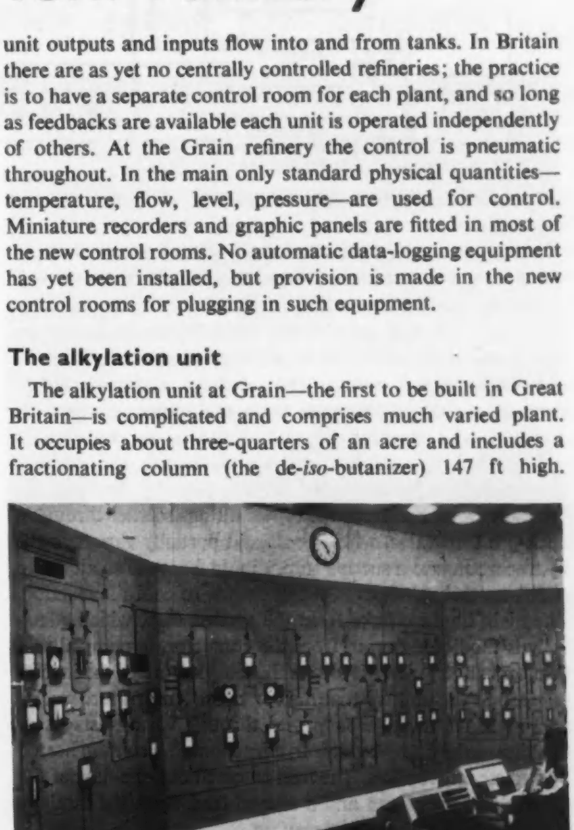
Although oil refineries deal with only one raw material (petroleum or crude oil) they have many end products—butane, aviation spirit, motor spirit, kerosene, diesel oil, gas oil, fuel oil, to name a few. Basically these products are produced by fractional distillation. One of the main difficulties facing the production controller of a refinery is that the relative demand for these different products fluctuates. Luckily by suitable processes other than the basic distillation lighter fractions can be built into heavier ones (e.g. alkylation) and heavier fractions can be broken down into lighter ones (e.g. catalytic cracking). As can be seen from the simplified flow chart of the Grain refinery several new kinds of plant are included among the additions, and these enable better use to be made of the constituents of petroleum to meet market conditions. Moreover aviation spirit is now being produced in Kent; the decision to provide plant for this was not unconnected with events in Abadan, but it is interesting that, despite the growing number of jet aircraft, BP foresee a full demand for the additional output of aviation spirit for piston-engined aircraft.

Independently controlled units

It should perhaps be made clear that each unit in an oil refinery is physically separated from its neighbours and that normally there is no direct flow from one unit to another; unit outputs and inputs flow into and from tanks. In Britain there are as yet no centrally controlled refineries; the practice is to have a separate control room for each plant, and so long as feedbacks are available each unit is operated independently of others. At the Grain refinery the control is pneumatic throughout. In the main only standard physical quantities—temperature, flow, level, pressure—are used for control. Miniature recorders and graphic panels are fitted in most of the new control rooms. No automatic data-logging equipment has yet been installed, but provision is made in the new control rooms for plugging in such equipment.

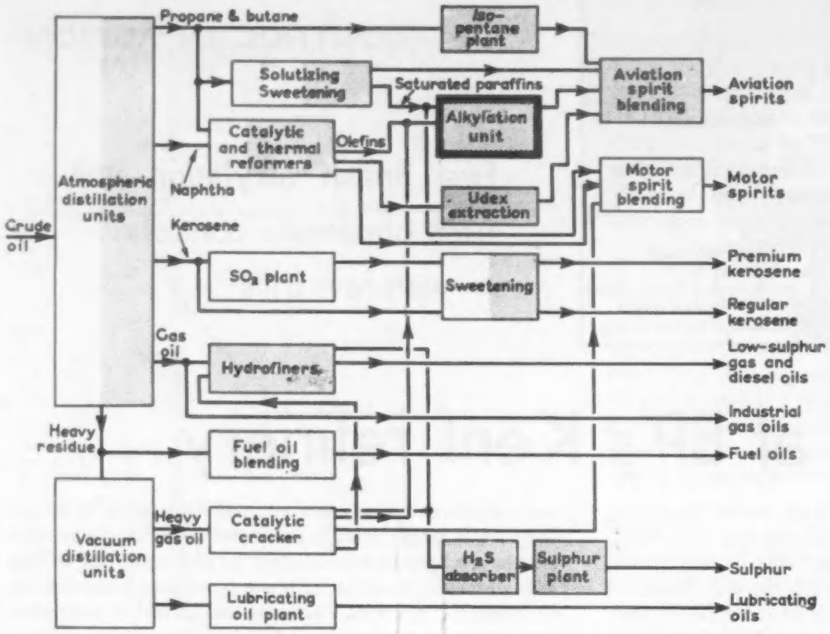
The alkylation unit

The alkylation unit at Grain—the first to be built in Great Britain—is complicated and comprises much varied plant. It occupies about three-quarters of an acre and includes a fractionating column (the de-*iso*-butanizer) 147 ft high.



The alkylation unit is controlled from this centre where miniature recorders control indicators and coloured flow lines display process information on a graphic panel of clean and modern design

Alkylation is the combination of saturated paraffins, such as butane and *iso*-butane, with unsaturated olefins, such as butene and *iso*-butene, to form alkylate. Olefins are rarer than paraffins; they do not exist in crude oil and are produced by cracking. The process requires a catalyst, which at the Grain refinery is sulphuric acid. A paraffin/olefin ratio of about 500:1 is used so that the olefins are largely swamped, and



Simplified flow chart of the Grain refinery. New plant is shown by tinted boxes. Many of the boxes represent several separate plant units taken together

SO₂ PLANT
Sulphur dioxide at a low temperature is used to dissolve aromatic compounds and separate them from kerosene.

CATALYTIC AND THERMAL REFORMERS
These convert low-octane heavy naphtha into motor spirit and similar products.

UDEX EXTRACTION
This produces from catalytic reformate an aromatic for blending in aviation spirit.

SOLUTIZING
Removing sulphur.

SWEETENING
Conversion in copper-chloride plants of corrosive and evil-smelling sulphur compounds.

HYDROFINERS
These remove sulphur from gas and diesel oils by combining it with hydrogen to form hydrogen sulphide.

polymerization, extravagant in the use of olefins, is discouraged.

The reaction takes place in a large horizontal cigar-shaped vessel called a *contactor*, where chilled paraffin/olefin feed meets the sulphuric acid and is mixed with it by a turbine-driven agitator. The reaction time takes 20 minutes so that the flow into a contactor must be adjusted to renew its contents completely in this period. The resulting mixture is forced from the top of the contactor to an acid settler, in which the sulphuric acid separates out and returns to the contactor.

The reaction in the contactors is exothermic and the heat generated must be controlled. This is done by 'flashing' the liquid hydrocarbon from the top of the acid settler through a back-pressure valve, which cools and partially vaporizes the hydrocarbon into a suction trap. Liquid from the suction trap circulates through coils in the contactor to cool the reaction. The main liquid offtake from the suction trap, which effectively is the liquid output from the contactor, is pumped to a heat exchanger, where it lowers the temperature of the incoming feed to the unit, so that the contactor temperature can be held at 35-45° F. It then passes through various stages of washing to the de-*iso*-butanizer, a fractionating column heated by two steam reboilers. The feed enters about one-fifth of the way down the column and a second feed, from the catalytic reformer, enters about half-way up.

The 'overheads' from the top of the de-*iso*-butanizer column consists mainly of *iso*-butane. This is condensed and some returned to the column as reflux, while the remainder is either recycled or fed to storage tanks. The 'bottoms' of the column are fed to a de-butanizer—another column with reboiler—and the 'bottoms' from this form the required alkylate. In a re-run tower the alkylate is vacuum distilled into light alkylate (for blending in aviation spirit) and heavy alkylate (for blending in motor spirit). The normal ratio by volume of aviation to motor spirit produced by the alkylation unit is about 30:1.

Instrumentation and control

Well situated at one end of the plant, the control room has a large window that gives the operator a clear view along the central alley through the unit. The graphic panel, which was designed and installed by Lummus Ltd, the main contractors for the alkylation unit, is finished in green, and four different colours are used for the flow lines of the various process constituents. Taylor miniature pneumatic recorders are used with Sunvic two-term and three-term controllers mounted on their backs. As is customary in much process plant the three-term controllers are used only for temperature and a few selected pressures. Air purging of electrically operated indicating instruments is provided.

For temperature measurement Sangamo Weston resistance bulbs are used with a 60-point temperature indicator (made by Honeywell-Brown). In addition seven temperature values are automatically controlled, with Taylor Transaire pneumatic transmitters as the detecting elements. Plastic-covered cables having 19 cores of copper pneumatic tubing are used for the connexions to and from the control room. These are run into junction boxes above the graphic panel and at various points out on the plant. Most of the diaphragm-operated control valves in the plant are made by Fisher Governor.

Gas analysis

Probably the most interesting instrument used on the alkylation plant is a Metropolitan-Vickers gas chromatograph, shown at the IEA Exhibition this year. This is sited at the foot of the de-butanizer column and works with a Sunvic full-size potentiometric recorder in the control room. It is used for gas analysis of the de-butanizer overhead vapour, i.e. the fraction from the top of the column. Normal butane is the predominating constituent but mixed with it are *iso*-butane, *iso*-pentane and pentane. The chromatograph operates by passing a sample of the vapour through a column containing brick dust impregnated with an organic compound. The organic compound has varying affinities for the different constituents which allows them to be stripped out in turn by a stream of air. By comparing the thermal conductivity of the stream with the conductivity of a reference column of air at the same temperature the proportions of the constituents can be found. The flow rate is such that a complete sample

passes through the instrument in twenty minutes. A single record on the chart has four peaks and the areas beneath these correspond to the amounts by volume of the four constituents present. Trials are still proceeding on this instrument, but, when operational, it will cut down the period for analysing the de-butanizer overheads from three hours (as carried out in a laboratory) to twenty minutes.

Between the window and the graphic panel in the control room is a small control desk. On this is mounted the multi-contact switchboard for temperature measurement, and an electrically operated automatic alarm logger, made by Evershed & Vignoles. This sounds an alarm if one of twenty selected variables strays outside specified limits. It automatically prints the time that the alarm occurred and the time that correcting action is taken. The alkylation unit is the first at the Grain refinery to have automatic alarm logging.

In the two months that the alkylation unit has been on stream, the instrumentation and control equipment (apart from the gas chromatograph) has operated perfectly, owing to the intensive precommissioning checks made by the contractors and refinery staff. The unit will not be shut down—unless an emergency arises—for another nine months.

Control of the National Grid

New system now completed

THE NEW GRID CONTROL centres at Birmingham and Manchester went into full operation recently, marking the end of a plan devised nearly ten years ago by the CEGB and three manufacturing firms—the Automatic Telephone and Electric Co, The General Electric Co, and Standard Telephones and Cables. The plan was to standardize on telemetering equipment and replace the earlier centres by seven new GCCs. These—at Newcastle, Leeds, Manchester, Birmingham, Bristol, Redbourn and East Grinstead—are now all in operation.

Each centre is in direct communication by means of rented GPO lines with National Control in London and with all the power stations and main switching points in its area to give coordinated operation of the grid, which, dealing with a total capacity of 22 000 MW, is the largest system under unified control in the world. During the full twenty-four hours of every day this system control organization is checking costs of generation, planning generating programmes and issuing instructions for generating plant to be started up or shut down, so as to meet the constantly changing demand for electricity at the lowest possible overall cost. Those stations that can generate most cheaply are used to the maximum extent, and the older, more inefficient stations as little as possible.

The largest display in a typical GCC control room is the mosaic switching diagram. Made up of thousands of interchangeable plastic squares portraying various items of transmission equipment and switchgear, and coloured to represent the appropriate system voltage, it is usually about 50 ft long and 9 ft high with 1500 or more semaphores for breakers, isolators and earthing switches. All switching operations are recorded here—the circuit breaker positions being shown automatically. Facing the diagram are two switching desks equipped with keyboard answering and priority calling of all stations in the area. From the desks the engineers give switching instructions and issue permits-to-work.

Slightly smaller in size is the feeder flow diagram. This incorporates about 100 telemeters in mimic power lines which indicate the magnitude and direction of active and reactive power flow in the various lines and transformers of the 275 kV Supergrid and most of the 132 kV lines. In each line a red lamp flashes when the current exceeds a preset value, while at the line ends green lamps light whenever the switchgear opens the line. From a loading desk in front of the display, engineers continually regulate generation in accordance with

Round the clock control of all power stations operating in the North Thames area is exercised from this centre at Redbourn. Power flow through the various grid lines is continuously metered to the feeder flow diagram on the right and the position of all circuit-breakers in the area is automatically shown on the switching diagram (left)

the requirements of the consumers and economy considerations. One of the most direct of the influences on consumption is daylight intensity, and this is telemetered to the loading desk from the area's main industrial centre. In front of the engineers chart recorders indicate area net transfer, total generation and system frequency. Other instruments indicate rate of change of frequency, and a 16-way message instructor for the various out-stations is incorporated.

GPO lines still used

The standardized system continues the established practice of using rented GPO lines as the main channels of communication. Frequencies used are: (a) d.c. or 300 c/s for instruction, indication and telephone signalling, (b) 400–2000 c/s for speech, interrupted at 480 c/s for ringing and busy tones, and (c) 2220 and 2340 c/s for telemetering.

The d.c. or 300 c/s signalling channel is used for the transmission of signals to the GCC where they are made to record automatically the position (open or closed) of any Grid circuit-breaker at remote stations. The same channels are used from the stations to signal telephone calls and the indications of

automatic isolators, overloaded feeders, direction (import or export) of telemetered power transfers, loss of telemeter channels between stations and acknowledgment of visual message instructions. To prevent lock-out due to channel congestion during heavy traffic, the selection, indication and telephone signal trains use the common signalling channel in turn. From the GCCs the channel is used to select visual messages or generation instructions at the stations and to set up telephone calls.

Relays were unsuitable

When an indication train is transmitted from a satellite station it is passed on to the GCC by the parent station, which together with the other satellite stations is then prevented from sending an indication train. With an additional group selection code, selection trains from the GCC are relayed by the parent station into the local equipment or to the selected satellite.

The telemetering channels transmit up to twenty or more continuous meter readings over one GPO circuit for display at the GCC, all unaffected by speech or signals traversing the same line. The telephone relays used in the past with individual signalling channels have given way to electronic equipment in a modern multiplex system. This uses start-stop time division with 20 millisec marking and scans ten meters in 200 millisec three times a second. In the GCCs the decoded impulses operate electronic telemeters to produce direct voltages directly proportional to the impulse rates.

The standardized system has now been in operation for several months in some areas and the CEGB says that operational experience has been 'most gratifying'. A new national centre is planned to take the place of the temporary headquarters in Bankside house, and this should be in operation within two years.

Industrial photoelectric control

has passed Inter-Services test

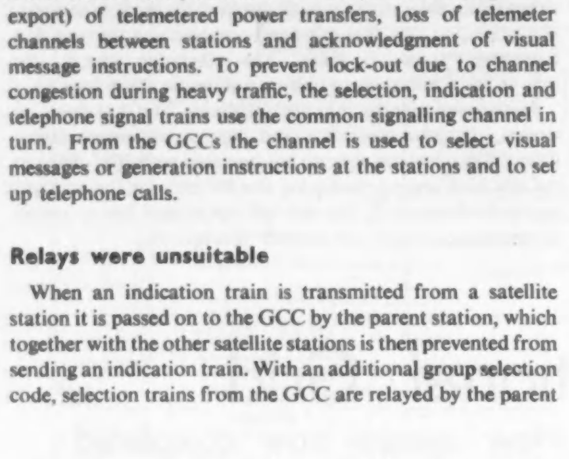
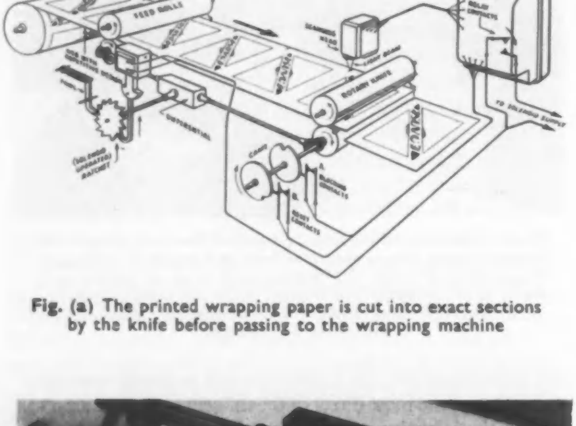


Fig. (a) The printed wrapping paper is cut into exact sections by the knife before passing to the wrapping machine



courtesy of Van den Berghs & Jurgens Ltd

Fig. (b) The photoelectric sensing head with its adjusting frame has been offset so that the register mark can be seen clearly

THE PHOTOELECTRIC sensing head and relay unit which is described here has no startling new features, but the novelty lies in the philosophy of its design and of the tests that have been made upon it. It was designed from the first to work under the most arduous conditions, and in fact it has passed the searching requirements of an Inter-Services heat, humidity and endurance test. As one of its requirements this test insists that the apparatus must work for eighty-four days, during which time it is exposed to various destroying influences. The units will work under water and when installed in a food factory they are usually cleaned by high-pressure steam hoses.

One interesting application of the sensing head has been to registration control, and for this it has been installed in many of the Unilever factories, both in this country and abroad. In the packing of products, such as margarine, soap or sausages, it is essential that the design on the wrapper bears the right relation to the product. This means that as the strip of printed wrapping paper is drawn off a roll it must be cut at an identical position between each wrapper, so that the design appears at the same place for every article. It is not possible to have the paper cut at a fixed distance as the dimensions of the paper change with uneven drying of the printing ink, slippage of the draw rollers and stretching of the paper. The error in each case may be small, but with a roll of paper feeding up to 300 wrappings per minute into a packaging machine, they can quickly accumulate and the design will assume a variety of positions. Several methods have been tried in an attempt to overcome this problem but the most popular one today is that of photoelectric control. A mark is printed with each design in a place where it is clear of other printed matter. This register mark is detected by a photoelectric scanning head which controls the cutting knife to produce identically cut wrappers.

The paper in the one-way registration control Fig. (a) is underfed into the machine, i.e. the speed is lower than that required to maintain the desired flow and in this way the

error accumulates in one direction only. A two-way registration control is more elaborate and can correct errors in both directions. Usually the machine is started with the register mark in advance of the true register by an amount equal to the maximum allowable error. Because of the underfeeding the register mark will gradually come to the true register and then start to lag behind. When it has lagged behind by an amount equal to the maximum allowable error it will be corrected by an amount equal to twice this error, which will bring it to its original position in advance of the true register. The underfeeding is set at a rate which will make a correction necessary at a number between four and twenty-four patterns, the number being set by the operational speed.

From Fig. (a) it can be seen that the angular displacement of the rotary knife to the feed rolls can be varied by a differential in the driving shaft which connects the knife and rolls together. A single movement of the solenoid-operated ratchet will cause the rotary knife to be advanced by an amount equal to twice the maximum allowable error.

The scanning head shown in Fig. (b) is completely sealed and watertight. In the Figure the head has been moved to one side so that a clear view of the register mark can be obtained. Normally it would be directly over the mark, and the cell would detect the difference in the reflected light when a mark passed beneath it, which may have a thickness of the order of 0·005 in.

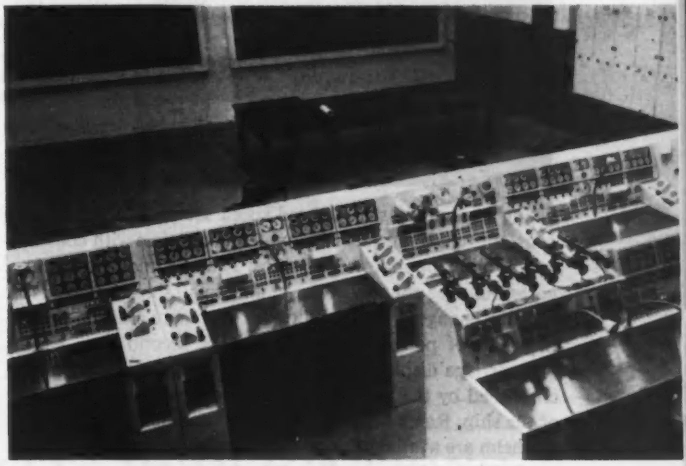
The blocking contacts A are opened once for every revolution of the rotary knife. If the registration error is within acceptable limits then the signal from the photoelectric cell is blocked. However, if the error becomes equal to the maximum the contacts will be open at the time the register mark passes beneath the scanning head, and the signal from the head will be used to actuate the ratchet. On rotating 180 deg from the point at which contacts A opened, contacts B open momentarily to reset the control in readiness for the next correction, which may come 1/10 sec after the first.

The equipment is manufactured by Electronic Switchgear Ltd and was designed in close cooperation with the engineers of Unilever Ltd and Van den Berghs and Jurgens Ltd.

The Action Speed Tactical Teacher

Fighting sea battles in the classroom

TO STAGE even a limited naval exercise costs several million pounds, and a British development by which sea 'battles' at action speed can be conducted from cubicles in a classroom is proving increasingly popular overseas. Among the countries which have had these Action Speed Tactical Teachers so far are Australia and the United States, and orders have now been received from Canada, Pakistan and Spain by Redifon Ltd, who undertake the supply of complete installations. The training exercises can simulate aircraft, surface ships and submarines. Each craft is controlled by students from a cubicle representing the operations room, and the resulting movements of the craft are thrown onto a cinema screen by a spot of light from a projector. The progress of the whole exercise is watched and monitored by instructors at the main control desks in front of the screen.



The whole scene of the 'battle'—watched and monitored by instructors at these control desks and conducted by trainees from their cubicles—is projected onto the left-hand screen; the auxiliary screen to the right is used for blown-up displays of any part. Facilities include six hand-operated projectors (foreground) for displaying torpedo tracks

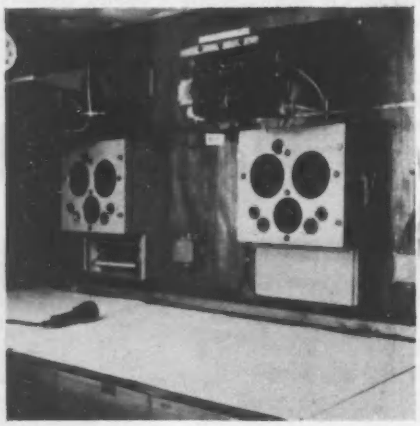
Area can vary from 25 to 1600 miles square

The latest tactical teacher is the one installed at the RN Tactical School at Woolwich and details of this are given by W. G. Heatley and A. E. Davis of the RN Scientific Service in a recent Admiralty Bulletin. Twenty-nine projectors are incorporated, including one which projects a pattern of spots representing a convoy, and the precision is such that errors are less than ½ in. anywhere on the 12 ft square screen which is 40 ft away. Each projector receives M-type transmissions of northing and easting components of the craft's movements, and these transmissions turn leadscrews to move the outboard guide for the projector torch in a plane which is accurately adjusted to be parallel to the screen. The exercise area displayed may be 25, 100, 400 or 1600 miles square, the change of scale being made by a speed-change gear in each transmission which is incorporated in the setting-up units—known as the Lining-up Indicators.

Each ship is represented by its operations room, which receives the information it would have as an independent ship manoeuvred under its own command. This includes its own plotting facilities, a display of the radar situation about itself and five channels of simulated radiocommunication. Direction-finding information is provided by the instructors acting as the ship's asdic and d/f offices reporting to the

operations room. Enemy craft can be controlled by the instructional staff, or 'sides' can be played with any combination of ships, submarines and aircraft.

For convenience, the control of ship's speed and course is effected in the operations room. On the earlier models, a speed and helm unit was used giving an output of ship's course by M-type transmission and speed by log impulses. This output is fed to a standard plotting table, where it is resolved into northings and eastings. Output transmitters are fitted to the table coordinate drives and these supply the projector. The speed and helm unit comprises a constant speed motor driving ball-and-disk variable-speed gears. The ball carriage of one v.s.g. is displaced according to ship's speed and its output roller drives a contact-making cam giving log impulses. A desired speed set on is achieved at a constant rate by means of a hunter mechanism with constant-speed follow-up motor. Two rates, $2\frac{1}{2}$ and 5 knots per minute, corresponding roughly to large and small ships, are available by gear change and in addition a fast acceleration simulating that of patrol boats is fitted. The second v.s.g. has its ball carriage displaced according to helm, set on by a wheel controlled by the helmsman, and its output alters the course of the ship. Rates of turn of 80°, 120° and 800° per minute at full helm are available by gear change, simulating large ships, small ships and fast patrol boats respectively.



The operations room of each craft is represented by a cubicle which receives the same information—including radar display—as it would in a real battle. Using a control unit, plotting table and radar display in the case of a ship cubicle (left), and control unit and ground position indicator for an aircraft cubicle (right), trainees control the craft's movements: these are transmitted to a projector which throws a spot of light onto the screen

Radar development will aid plotting

The purpose of the Woolwich tactical teacher is somewhat different from others, and it was decided to design the Ship Control Unit so that a new course could be set on quickly and the ship would turn to this course slowly, according to an angle of helm which would be set on independently, the idea being that alterations are generally made at an angle of helm of say 15° which could be left set on. Again a slave plotting table is used and a new table incorporating projection of the radar display onto the plot is under development, with the object of facilitating plotting of other ships.

Aircraft have a simplified speed and course unit: speed is set directly without acceleration delay, and a new course is achieved at one of three selected turn rates. Resolution into northings and eastings is again carried out in the control unit and the transmissions operate a Ground Position Indicator, which displays the aircraft's movement on the chart by a projected spot of light. Provision is made for carrier-borne aircraft to be linked with the parent carrier for movement when 'on deck' so that, on flying off, they start from the carrier's position.

Information on the course and speed of ships and aircraft is repeated to dials on the controllers' desks, and each controller has facilities for monitoring any of the communications channels in which he is interested, and for speaking on the Exercise Line to any cubicle. In addition, signal lamps for each ship indicate if radar is in use or a search receiver is being operated—also if gunfire has been opened and, in the case of submarines, whether surfaced, at periscope depth or fully submerged. The instructors are thus kept completely informed of the progress of the game throughout, and can exercise control at any time. At one console sit the tellers, whose job it is to give radar information—usually in grid references obtained from the display screen—to the plots of individual ships or groups of ships. This substitutes for individual radar offices in each ship 'telling' to the plot, and may not be required when the new plotting table with projected radar display is fitted.

New weapons can be 'tried out'

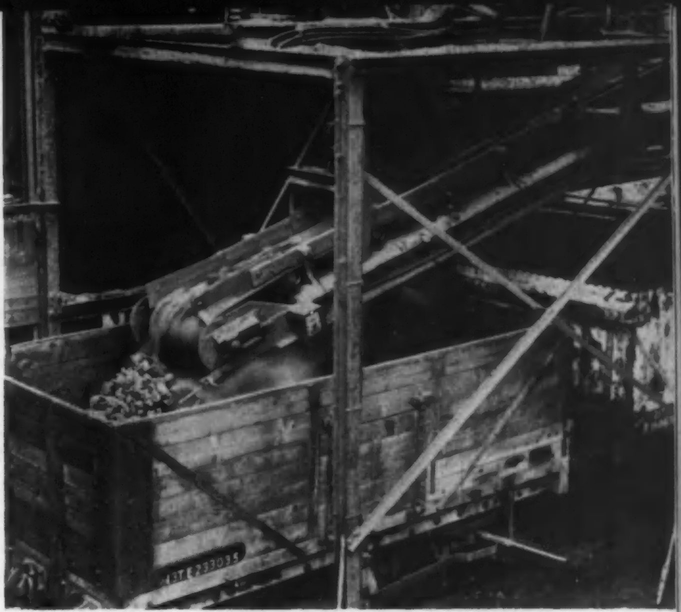
The ASTT radar system has to provide for the display of up to 48 targets on each of the individual Plan Position Indicators in the cubicles with limitation of the display on each to targets within radar range. To achieve this economically, a type of 'filtered' display has been adapted: each target in succession is displayed, if within range, as a small spot, the succession of points being at 25 targets per second and the whole cycle of painting repeated every two seconds. A range limiting amplifier associated with each observing craft interrupts the painting pulse so that display of the range of the target never exceeds a value dependent on the size of the target and the nature of the observer.

Behind the cloth of the main screen is another, made of Perspex, and the spots of light from the projectors show through onto this. While the exercise is in progress a team of plotters records the tracks of all the vessels, and when the exercise is completed the cloth screens are rolled up and the tracks on the Perspex displayed by edge illumination for the post-mortem.

One of the great advantages of the ASTT is that new weapons and devices not yet available in the Fleet can be simulated and their effects on tactics evaluated. A smaller version has been employed at Malta for three years by the navies of the NATO nations of the Allied Command in the Mediterranean, and has been found very useful for spotting differences of language and procedure immediately, without having to await a return to harbour to discuss them.

Instruments help coke loading

NCB breakage problem eased



The probe actuates a level controller timer so that the boom is automatically raised a little at a time. In the past, constant adjustment of boom height was needed

ONE OF THE PROBLEMS faced by the National Coal Board has been the complaint by many customers of the high percentage of dust and small pieces. To remedy this, automatic and semi-automatic devices are now widely used for loading into railway wagons and colliers. Typical of these is a method employed at the Wingerworth coke producing plant in Chesterfield. Coke from the plant goes to industrial and domestic consumers over a large area, and following complaints an investigation was carried out by plant officials to pinpoint the main cause of breakages. It was found that most of them occurred when the coke was loaded into the railway wagons by boom loaders. One operator often had to supervise two or more booms and in practice he would usually be reduced to setting the lower end of each about four feet above the wagon floor and hoping for the best.

An instrument firm—Fielden Electronics—was approached, and in conjunction with NCB engineers devised a system to raise the boom automatically as a wagon fills up. On the end of the boom is fixed a Tektor level controller timer which controls the steering gear of the hoist motor. When the wagon is in position under the loader all the operator has to do is to start the boom on its way down. When the level controller probe touches the bottom of the wagon the timer is actuated, allowing the boom to rise for a preset time. This is usually fixed as long enough for it to lift about six inches, and the conveyor motor then starts automatically. A gate opens to allow coke to run onto the loader and form a heap under the end of the boom. When it nears the probe the resulting change of capacitance actuates the relay in the Tektor and the cycle is repeated, so that the coke never falls through more than six inches. After a certain height is reached the wagon is moved along slightly and another heap started.

Three heaps are usually sufficient to fill the wagon, and the NCB says that the time taken with the new system—which has considerably reduced customers' complaints—is if anything a little shorter than before.

INDUSTRIAL PUBLICATIONS

The first issue of the new Research and Control Instruments Ltd house magazine has appeared. The *RCI Standard* is a well-produced and readable magazine in newspaper form.
Tick **No 130** on reply card

Sunvic Ltd have issued a diagrammatic leaflet on self-contained and remote **set controllers** and their miniature panel control stations, together with a second leaflet devoted to their **indicating control** station. A third leaflet briefly describes their **cold junction boxes,** designed for plant installation when a large number of thermocouples are situated at a distance from their indicating or measuring points. A further leaflet describes their miniature recorder, which can be used as a control station.
Tick **No 131** on reply card

The British Thomson-Houston Co have published a pocket book on the **installation and maintenance** of electric motors and control gear, a subject to which they attach much importance. The pocket book contains many diagrams and photographs, intended to assist maintenance staff.
Tick **No 132** on reply card

A well-illustrated catalogue of successfully tried and new **electric actuators** is available from the Plessey Co.
Tick **No 133** on reply card

Texas Instruments Ltd announce that a series of semi-conductor Application Reports will be published at monthly intervals, providing a continuous service of information relating to the use of Texas Instruments **silicon semi-conductor devices.**
Tick **No 134** on reply card

The Termination Equipment Co have produced a folder designed to provide an easy reference to their various products, including **inter-locking terminal blocks.**
Tick **No 135** on reply card

A generously illustrated booklet deals with Schrader's various products designed to utilize **compressed air.**
Tick **No 136** on reply card

Sinex Ltd have issued a catalogue on their **precision installations** for controlled movement.
Tick **No 137** on reply card

Reynolds & Branson Ltd have produced a folder describing equipment for controlling the **temperature and humidity** in both research and control laboratories.
Tick **No 138** on reply card

Pick-off

by '*UNCONTROLLED*'

Amid all the welter of discussion and doubt which development of long-range nuclear-headed missiles has caused among thinking people I find Mr Aubrey Jones's recent news that Britain is now actively developing some defence against them rather cheering. We have, it seems, a device that will detect the launching of a long-range missile up to a distance of 1000 miles. On whatever basis it works it patently needs extending up to the maximum range of any enemy missile. But a far greater difficulty than the detection of a missile being launched towards us will be its interception in flight, and its explosion over enemy territory, the sea or sparsely populated areas of allied countries. Owing to the high speeds the control problem of guiding a missile to catch a missile will be prodigious; but not insuperable, as our progress in rocket control since 1945 demonstrates.

Surely it is not old-fashioned to feel that while trying to do everything she can to avoid war, a nation should, together with her allies, strain her available resources to *defend* her people against attack. I remember a senior officer under whom I served in the 1939–45 war once declaring to me that one reason why Britain was always so unprepared at the beginning of wars was the reluctance of Service Departments in peacetime to spend much of their hardly won money on *purely defensive* weapons. It was, to put it crudely, more exciting to develop offensive weapons that promised spectacular results should war come. Though this attitude probably obtained in the past, I am sure it has disappeared today. The excitement and glory of war have departed. Nevertheless we have, I feel, been relying too much on the threat of retaliation during the last ten years. That the *best* means of defence against nuclear weapons is attack is true only in so far as attack is the *only* means. Any other means if it is foolproof or nearly so may be just as useful a deterrent. Hitler did not use poison gas in the last war only because he knew we could use it too; he appreciated that both the British Services and civilians had gas masks.

Visitors to the Portugese Industrial Fair—so *Time* reported—could 'play ticktacktoe with an electronic machine that cackles mockingly when it wins and snarls menacingly when it loses'. I have no idea what 'ticktacktoe' is—perhaps some reader will tell me—but I am all for introducing gamesmanship into the ruthlessly successful automatons that take on all comers at nim or noughts and crosses during scientific exhibitions and conversaziones. Gamesmanship is essentially humanizing. When Cybernetics invades the Theory of Games I imagine that Potter's Hypotheses will be its main contribution.

Like most people living in or around London, I only occasionally visit the permanent collections in London's art galleries and museums. We usually waste opportunities that are always available to us unless we are often reminded of them. However a museum I do visit at intervals is the Science Museum—the 'best free entertainment in London'. Sometimes I go alone, but recently I spent part of a Saturday morning showing two boys aged five and six some of the museum's contents.

As it happened the only real example of automatic control equipment I could find in the Children's Gallery was performing rather erratically—and that bothered me more than the boys. The exhibit consists of a short passage, ending in a door, which can be opened automatically by someone in the passage who interrupts a beam of light falling on a photocell, and thus trips a controlling relay. I remembered the exhibit from pre-war days and I do not think it has been changed since it was first set up. Now the door tends to stay open the whole time; after some thirty years of operation boys have 'flogged the life out of it' as one of the attendants put it to me. I gather that a large electrical firm is likely to present the museum with a new control unit; meanwhile perhaps the exhibit could be modified to one showing the evil effect of relay contact wear.

Much as I enjoy nosing round the Science Museum, I always feel that the museum authorities err in mixing their historical and educational functions. The first is to house a collection of scientific relics and specially built models, dioramas, etc, to exemplify the development of science and technology. The second is to arrange exhibits to present modern technological practice. Those who visit the museum to inform themselves about, say, the internal combustion engine or telecommunications may be hard put to pick out up-to-date exhibits. Could we not have a separate gallery of equipment and models illustrating important facets of engineering and industrial practice, which are frequently changed to move with the times? Doubtless this would imply more resources than the Director of the Science Museum at present commands, but the Minister of Education would not be wasting public money in making them available. A gallery of the kind I envisage would be enthusiastically acclaimed and would help towards making the British public more technically interested and more proud of their country's industrial prowess. But the Minister would also need to stimulate the museum's publicity: at present this is almost non-existent.

The British Association has embarked on a new drive to make the public better informed about science, as was announced during the BA's annual meeting at the end of last month in Glasgow. I hope the BA's officers will not overlook the heuristic potential in Exhibition Road.

Shortly before he left for Canada at the end of August, I had a talk with Dr G. L. d'Ombrain, who told me something of his plans for control engineering courses at McGill University, Montreal. Dr d'Ombrain was appointed Chairman of the Electrical Engineering Faculty at McGill in January, and he came to England in the Long Vacation partly in order to meet further candidates for the newly founded chair in control engineering at McGill—the first in the English-speaking world. The initial control engineering courses at McGill will be postgraduate ones, but undergraduates specializing in mechanical and electrical engineering will have a sprinkling of lectures on control from the third to the fifth year of their courses. Computer techniques will be prominent in the postgraduate courses and Dr d'Ombrain is hopeful that the university will shortly possess both an analogue and a digital computer, which can be used for research and instruction. Looking to the future Dr d'Ombrain foresees an increasing emphasis on control in undergraduate courses and eventually—perhaps six years ahead—first degrees in control engineering.

Another emigrant to Canada from the small number of lecturers in control technology in British universities and technical colleges is Professor A. Porter, who was due to leave on 10th September to become Dean of the College of Engineering at Saskatchewan University. He tells me that he is expecting to dabble in politics when he is in Canada, for many state politicians are recruited from university dons. He will be much missed at Imperial College and his place will be hard to fill; but I hear rumours that there will be changes in the organization of the Electrical Engineering Department there and that the chair Dr Porter occupied will be suspended in favour of a new one.

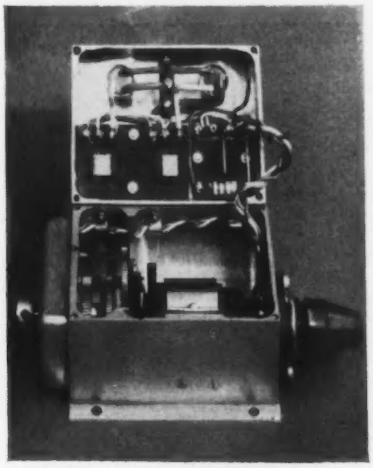
New for Control

A monthly review of system components and instruments

SERVO UNITS

are compact, powerful

Servo Units Ltd, the subsidiary of Harvey Electronics Ltd, have produced an improved version of their servo units incorporating the features of the earlier Harvey servos: light weight, accuracy and high torque with the minimum of moving parts.



The interior of a servo unit

The previous version relied upon a vibrating relay to provide high torque without overshoot. In the new series the motor is fed via power transistors controlled either from a d.c. transistor amplifier, or a thermionic amplifier supplied from a transistor h.t. supply, all fed from the original d.c. supply. Mains a.c. supply units are also available. The size of the smallest (type 0.TR) of these servos is 3·0 × 2·25 in.; has a stalled torque of 1·0 lb–ft with a rate of response of 35 deg/sec; and has a repeatability of 0·2 pc full scale on light load, and 2·5 pc. on 90 pc full torque. Type 1.TR is 4·10 × 2·55 × 2·50 in.; stalled torque 5·0 lb–ft; rate of response 50 deg/sec; repeatability 0·2 pc, and 2·0 pc. under 90 pc full load

Tick **No 111** on reply card

MODULAR GROUPING

sets computing pace

A new 'Pace' analogue computer (231R) has a modular grouping of components that it is claimed permits an operator to set up a problem four times faster than he could before. A 'prepatch panel' with 3450 holes eases the use of bottle plugs and shorter patch cords. The patchboard itself can terminate 100 operational amplifiers and associated non-linear equipment, and has completely automatic readout. Included in the equipment are 30 combination summing-integrating amplifiers, 45 summing amplifiers, 25 inverters, 10 electronic multipliers, 10 five-channel servomultipliers, 5 servo resolvers, 5 generators and 3 eight-channel recorders for X-Y plotters. A high speed digital voltmeter on the control panel indicates the voltage reading and the component address.

The 'Pace' computer is made by Electronic Associates Inc, who maintain a sales office and computer centre in Brussels.

Tick **No 112** on reply card

ELECTRONIC RELAY

increases switch capacity

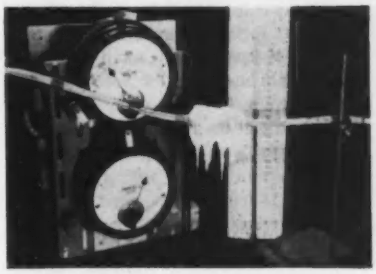
A new industrial electronic relay by Londex Ltd has been designed for increasing the switching capacity of delicate contacts. It will operate through an external resistance of up to 2 megohms and the connecting leads can be up to 100 ft in length. The main components are a small isolating transformer, a cold-cathode gas-filled valve and a Londex KR relay fitted with single pole change-over output contacts rated at 4 A 250 V a.c. or 2 A 440 V a.c. An indicator on the steel casing of the unit is illuminated when the electronic relay operates. The relay unit is available in two forms, depending whether completing the trigger circuit energizes or de-energizes the relay.

Tick **No 113** on reply card

UK-AN CONNECTORS

a step to standardization

The Plessey Co Ltd have designed a new range of plugs and sockets which are fully interchangeable with the American AN or MS connectors. The UK-AN range, as it will be known, meets the requirements of many stringent specifications. Two shell styles are available—fixed or free—and each can be supplied with either plug pins or socket inserts. The mouldings are made of silicone rubber and for normal wiring no accessories are required, the plugs and sockets being waterproofed and sealed merely by pressing the pins and inserts into the back of the moulding. The pins and inserts are silver plated and may be crimped or soldered as desired. The connectors have



A connector is hidden beneath the ice and is undergoing a test at — 60 deg C

passed a series of arduous tests, including humidity conditions up to 100 pc, flame resistance at 1100 deg C for 15 min whilst carrying the full rated current, and satisfactory working at temperatures from — 60 deg C to + 190 deg C. They can withstand a voltage of 5 kV at sea level and 2·5 kV at an altitude of 70 000 ft, and are pressure sealed up to 20 lb/in², with a leakage rate of less than 1 cm³/hour.

Tick **No 114** on reply card

ANALOGUE COMPUTER

is compact, convenient

The 'Minispace' is a small analogue computer that is completely self-contained and comprises ten drift-corrected d.c. amplifiers with all the necessary input and feedback components, potentiometers, control and patching panels and power supplies. The whole unit is contained in a small cabinet (51 × 20 × 30 in.) with the high stability

An operator on a stool can handle all the controls of the 'Minispace'

power supplies (400 mA at $\pm$ 300 V) mounted below desk level. Summing, sign reversing, integration, or the simulation of a transfer function can be carried out on each of the ten amplifiers. With the servo multiplier the 'Minispace' can be used as a multiplier, resolver, or non-linear function generator. For more complex problems two of the computer units can be coupled together to form a 20-amplifier computer.

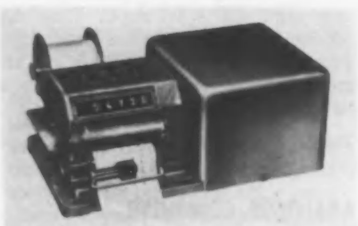
The 'Minispace' and servo multiplier (TJ 725) are made by the Solartron Electronic Group Ltd and were shown for the first time at the Farnborough air show.

Tick **No 115** on reply card

ELECTROMECHANICAL COUNTER

prints record

A new electromechanical counter has been designed which will provide a permanent printed record of a variety of measurements. It is available in models to suit different applications, which include the counting of electrical impulses up to a rate of 5/sec, the



Provides a printed record of a variety of measurements

recording of elapsed time in units of 0·01 min or sec and the counting of shaft revolutions up to 50/sec. The count is printed in numbers of up to six digits on a paper roll 2⅜ in. wide or on cards. An automatically changed serial number or hand-adjusted code, consisting of two figures or letters, can be printed in addition to the counting digits. It can be applied to the recording of any variable, or the time integral of such a variable, that can be converted into electrical impulses or shaft rotation. The counter can be obtained from Radiatron.

Tick **No 116** on reply card

MULTI-RANGE METER

of unusual sensitivity

A sensitive multi-range meter, the Taylormeter '100 A', was shown by Taylor Electrical Instruments Ltd at the National Radio Show. The sensitivity of the instrument is 100 000 ohms/volt and it incorporates a 9 μA centre-pole moving-coil meter. The current range is 0·2 μA – 10 A. The resistance range is 0·5 ohm–200 megohms. The voltage range is 10 mV – 25 kV d.c. (2·5 kV a.c.). The '100 A' is claimed to be able to replace a valve voltmeter and to be suitable for everyday service.

Another new instrument by the same firm is the '127 A', which it is claimed is the first pocket-size multi-range meter in this country with a sensitivity of 20 000 ohms/volt.

Tick **No 117** on reply card

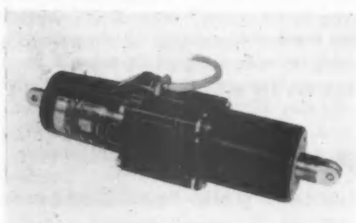
LINEAR AND ROTARY ACTUATORS

birds of a feather

A new range of linear and rotary a.c. actuators has been introduced by the Plessey Co Ltd. The units are fully tropicalized and will operate up to temperatures of 180 deg C.

The Eagle linear actuator weighs 5·5 lb and is powered by a 3-phase 400 c/s induction motor which incorporates a disk-type electromagnetic brake to limit over-run. Stroke length is adjustable from 0·1 to 2·5 in. and is controlled by two pairs of synchronized snap-action limit switches. The maximum working load is 750 lb and the maximum static load 4 500 lb. The Condor linear actuator weighs 4·5 lb and is of the twin motor type, the motors being equally disposed about the lead screw. It can be driven by either of the two 3-phase 400 c/s induction motors, each of which is fitted with a disk-type electromagnetic brake to limit over-run. The stroke can be varied between 1·4 and 2·0 in. Its maximum working load is 275 lb and maximum static load 1200 lb.

The Hawk rotary actuator is powered by a 3-phase 400 c/s squirrel cage induction motor with disk-type electromagnetic brake



The Eagle linear actuator

and gives an output torque of 60 lb-in. The final output shaft rotates at 1·07 r.p.m. giving 90 deg angular travel in 14 sec with an applied nominal torque of 40 lb-in. Angular travel is adjustable from 15 to 330 deg. The unit is fully tropicalized and weighs 1·87 lb. The Kestrel rotary actuator weighs 3 lb and gives an output torque of 85 lb-in.; it is driven by a 200 V 400 c/s 3-phase squirrel cage induction motor to provide an output speed of 30 sec for 180 deg angular travel. Alternative speeds of 60 and 80 sec for 180 deg are also available. The design incorporates a 200 ohm potentiometer to enable units to be operated in synchronized pairs. The braking is carried out by a drag mechanism incorporated in the gearbox.

Tick **No 118** on reply card

AIR-CONDITIONING CONTROL

first of its kind?

The manufacturers of the 'Transmatic' state that it is the first British air-conditioning electronic control system to make use of printed circuits and a transistorized amplifier. The system has a wide range of adjustment and will provide for fine control of motorized valves, damper-motors or

Air conditioning by electronics

sequence switching units. It is available for simple proportional control, for proportional control with either one or two stages of compensation and for averaging control.

A new solenoid valve for high viscosity fuels is designed for use with fuel oil at viscosities ranging from 200–1000 sec Redwood No 1 at pressures up to 300 lb/in².

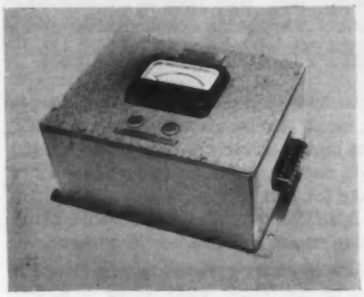
Both these pieces of equipment are made by Teddington Industrial Equipment Ltd.

Tick **No 119** on reply card

MAGNETIC AMPLIFIERS

are sensitive, robust

Two new magnetic amplifiers have recently been introduced by Parmeko Ltd. These robust machines, P2865 and P2866, are designed to measure and amplify small d.c. signals with a high degree of accuracy. They have a push-pull output of 0·25 watt (d.c. reversible polarity), which is large enough to drive either a pen recorder or several panel mounted instruments. They can also be used as pre-amplifiers for larger output



Designed to measure and amplify small d.c. signals

power equipment. The units are self-contained, have no valves, and when mains power is applied are ready for instant use. They operate from a mains supply of 200–250 V 50 c/s and have an optimum load resistance of 300 ohms. The P2865 is suitable for measuring from a voltage source such as a thermocouple and with a source of internal resistance of 900 ohms it feeds 30 mV into 15 000 ohms. The P2866 is designed to measure from a current source such as a barrier layer photocell and with a source of 7000 ohms it feeds 6·5 kA into 7000 ohms.

Tick **No 120** on reply card

DIGITAL COUNTER

with clear display

A new digital counter incorporates a crystal-controlled timer with an accuracy of $\pm$ 0·005 pc, and the overall accuracy is claimed to be $\pm$ 1 count, with a maximum rate of 10 000 counts/sec. The neon display provides an in-line readout visible at a considerable distance. The two versions in production are a tachometer, and a counter for random pulses up to 10 kc/s.

J. Langham Thompson Ltd, who make the digital counter, have also released details of a new range of transistor-regulated d.c. power supplies. Of the first three models to be put into production, one has a variable output of 4·5 to 14 V d.c. (regulation accuracy $\pm$ 0·15 pc) at 500 mA; and two have a fixed output of 12·5 V d.c. (regulation accuracy $\pm$0·1 pc) at 750 mA or 1·5 A. The variable unit weighs $7\frac{1}{4}$ lb and the fixed units weighs $4\frac{3}{4}$ lb.

Tick **No 121** on reply card

Digital tachometer

ELECTRONIC ENLARGER

perfect prints by auto-control

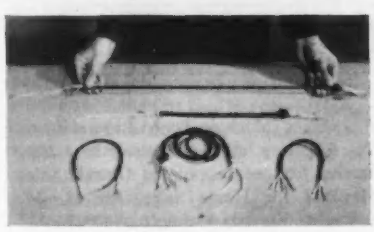
A new electronic photographic enlarger has been developed by the Graphic Arts Division of EMI Electronics Ltd. It is claimed to be the first of its kind in Europe and is designed to produce perfect results even from poor quality negatives. The negative is scanned by a light beam from a cathode-ray tube; and an electronic feedback circuit continuously varies the intensity of the scanning light beam during the exposure to compensate for varying densities in the negative. The scanning beam automatically brightens to 'burn in' highlights and dims to preserve shadow detail. The operator can select the desired degree of shading. A special light integrating system terminates the exposure automatically to produce a uniform print density without adjustment for widely varying negative densities. The enlarger prints from 35 mm up to half-plate and provides a maximum print area of 30 $\times$ 40 in.

Tick **No 122** on reply card

ELASTIC ELECTRIC CORD

innovation from Germany

The Electrolastic cord is an elastic electric cord with a maximum extension of 230–250 pc and a permanent deformation after 50 000 full extensions of about 3 pc. In a dry atmosphere the insulation resistance is



Stretching an electric cord

about 150 000 megohms. The silicon covered cords will maintain their full elasticity within the temperature range $-$ 60 to $+$ 100 deg C. The surface of the cords is straight and smooth and the cords may be obtained with up to eight individual cores. The manufacturers are Bevo of Western Germany, and the distribution in this country is handled by Mercia Enterprises Ltd.

Tick **No 123** on reply card

COLD JUNCTION BOX

cuts cable costs

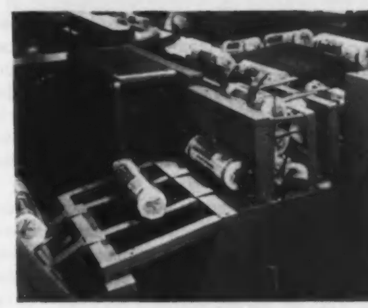
Sunvic Controls Ltd have produced a cold junction box for use when a large number of thermocouples are situated some distance from their indicating or measuring points. The unit accommodates sixteen pairs of copper-constantan leads, the sixteen compensating cables and a cold junction thermostat. The box can be installed on the plant and thermocouple leads taken to it for automatic compensation. The temperature is usually maintained at 60 deg C $\pm$ 0·1 pc.

Tick **No 124** on reply card

CHECK WEIGHER

can aid quality control

A high-speed electronic check weigher has been recently put on the market by the Automa Engineering Group Ltd. It is claimed that by the use of bridge and force-balance techniques the unit will work in



Fast, reliable weighing

factory conditions of vibration, humidity and temperature. Under these conditions 120 weighs per minute with a 2 pc accuracy can be achieved. The output from the weight transducers is fed to a discriminator which decides whether the object is over or under the correct weight. Facilities can be provided for counting and recording the weights. The unit can be incorporated into a feedback system which will regulate the processes affecting the weight.

Tick **No 125** on reply card

DECADE OSCILLATOR

sine and square waves

A decade oscillator has been shown which can provide a simultaneous source of both sine and square waves covering the audio frequency and extending into the ultrasonic range. The sine and square wave outputs are placed well apart to prevent mutual interference and to give easy identification. The four decade ranges cover the frequency band 10 c/s to 100 kc/s, with a maximum output of 10 volts for both sine and square waves. The oscillator (Mk 2, type 169) is made by Winston Electronics Ltd.

Tick **No 126** on reply card

We should like to apologize for a misnomer which we made in our August issue by referring to a display unit by Counting Instruments Ltd as a 'display tube'. In fact the unit is not a neon or filament display tube but employs an optical projection system with twelve lamps.

CUTTER WEAR COMPENSATION

an Appendix to an article published in July and August

by **D. T. N. WILLIAMSON,**

Head of Machine Tool Control Department, Ferranti Ltd, Edinburgh

Mr Williamson has prepared this short appendix to his article on the Ferranti system of numerical control of machine tools, since the problem of cutter wear was not covered in the article proper. It is a subject which excites much interest among users of numerically controlled machine tools, and there are, as Mr Williamson points out, different methods of tackling it.

Considerable misconceptions exist about the ability of a machine tool control system to compensate for cutter wear. It can be stated quite categorically that no machine tool control system can compensate for milling cutter wear. When cutter wear is detected, the only safe action is to remove the cutter and replace it with a sharp one, because any attempt to compensate locally by modifying the cutter path will produce errors at other points on the workpiece, since metal removal with a cutter which has lost its edge is affected by a large number of complex factors long before any change in diameter can be detected, and the error produced by defective cutting cannot be corrected by a simple displacement of the cutter centre track.

Two courses of action are possible: the cutter can be replaced by one of the same size and the machining continued immediately without any other modifications; alternatively the cutter can be taken away, reground and brought back to the machine to be used again. If the second course is followed, equipment has to be provided to displace the cutter path by a known fixed amount at right angles to the direction of movement. Both methods are practicable but there are sound reasons why the former method has been chosen as standard operating technique with the Ferranti system. These are:

a. The machine tool must be kept idle whilst the worn cutter is being reground, since, even if facilities are immediately available, this will take between thirty and sixty minutes. A substantial loss of production will result and the cost of the idle time of the machine will make the cost of this method of operation prohibitively high. It is difficult to resume the cut with a cutter of different size, without marking the work.

b. The cost of providing the necessary compensation equipment is not justifiable by any savings which could accrue from any method of its use.

c. The additional control given to the operator violates the concept, which has been found in practice to be accurate, that only the planner has the full knowledge which is necessary to be able to alter programming instructions, and unauthorized alteration can give rise to serious errors. For example, it is found that cutters are frequently used to form radii and to drill holes: if an operator were allowed to use cutters other than the specified size and to 'compensate' for them, such operations on the workpiece would be incorrect. Serious errors can also occur because interference with the automatic cutter radius compensation could give rise to conditions in which very high tool centre accelerations, which did not appear on the original programme, are demanded from the servomechanisms.

The alternative method of stocking cutters, which are reground in definite steps of size, and using a library of these cutters for numerically controlled work until they become useless, is the only one which allows the rigid control over cutter size and concentricity which is necessary for accurate numerically-controlled machining to be maintained, since all cutters come back to the tool stores and can be reground under quality-controlled conditions.

PEOPLE IN CONTROL

NYMAN LEVIN

K. F. CRAYFORD

W. J. PEARSON

BERNARD F. KANE

Mr George Campbell has been appointed General Manager of the Chemical and Metallurgical Division of the Plessey Co.

E. J. Jones (Machine Tools) Ltd announce the following staff changes. **Mr L. R. Newing** has been appointed Outside Sales Manager for Home Sales. **Mr H. M. Lebrecht,** formerly Manager of the Special Machinery Sales Division, has been appointed Inside Sales Manager and **Mr G. Cranston** has been appointed Area Manager for Scotland.

Dr Nyman Levin has been appointed a Deputy Director of the Atomic Weapons Research Establishment of the UKAEA.

Mr Bernard F. Kane has been appointed sales and technical representative for Marconi's Wireless Telegraph Co in Eastern Europe. He will operate from Vienna.

The Solartron Electronic Group announce that **Mr T. Morrison** has been appointed Instrument Sales Manager for the United Kingdom. The sales areas are being reorganized into three regional groups under **Mr Dennis P. Taylor,** South-Western Region; **Mr David R. Hall,** South-Eastern; and **Mr Terry Blacklock,** North of England and Scotland.

Mr K. F. Crayford has been appointed Sales Manager of the Government and Industrial Valve Division of Mullard Ltd. This embraces the Communications and Industrial Valve department and the Government Radio Valve Department.

The Fisher Governor Co announce that **Mr W. J. Pearson** has been appointed Sales Manager for the Continental range of butterfly valves which the company is now manufacturing in England.

Dr John A. Pople will take office on 1st October as Superintendent of the newly-created Basic Physics Division at the National Physical Laboratory, Teddington.

The Earl of Halsbury will retire in March 1959 from the position of Managing Director of the National Research Development Corporation.

Mr H. G. Bell has been appointed consulting engineer, Instrument and Meter Department of Metropolitan-Vickers Electrical Co.

The death is announced of **Sir Guy Locock,** a Vice-President of the Federation of British Industries, at the age of 75.

NEWS ROUND-UP

Computer trends in Russia

The development of computers and computing centres in Russia must be treated as a matter of urgency, says Victor Alexandrov, head of the State Planning Committee's designing bureau, in a *Pravda* article. He distinguishes three main trends in the development of computers in the USSR. The first of these concerns machines for scientific investigations and calculations. In this case electronic computers greatly reduce the time needed for solving a variety of problems. As an example, he mentions the part these machines have played in calculating the orbit of Sputnik III. The second trend is concerned with the use of electronic computers for controlling industrial processes in the chemical and metallurgical industries, in transport, etc. The 'automatic engine-driver', an electronic computer controlling the running of a train, which has been successfully tested on a railway line near Moscow, is a 'striking instance' of these control computers, he says. The third trend is the use of computers for economic analysis on a scientific basis. Electronic computers are being used to work out the economic links between various branches of the national economy. An example is the calculation of tables for the purpose of determining the quantities of raw materials, fuel and metal needed for carrying out economic plans. Alexandrov stresses that it is of paramount importance to make full use of the vast potentialities of these machines.

Large centres only are effective

'This is particularly important at present', he writes, 'so long as we cannot provide all the consumers with these machines. Practice shows that the most effective exploitation of this exact technique can only be achieved at special calculating centres equipped with computing machines of various types. The big force of, mathematicians, physicists and specialists in various fields of engineering who are needed in order to make all-round use of the potentialities of computers, can only be concentrated at such centres, and the problem of further developing them and creating a single state system is a very urgent one'.

A new development reported from Russia is the use of a special computing machine—the EIS electro-integrator—at the Petroleum and Gas Research Institute to analyse the exploitation of big oil deposits. Research carried out with the help of the EIS has shown that by intensive working of a layer it is possible to cut down the number of wells without reducing total output. Following the calculations at the Institute a field test was staged at the Bavli oilfields in Tataria. Half the wells were stopped up and it was found that the remainder could boost extraction sufficiently to maintain overall output of the oilfield at the same level. Another machine which may be useful in the oil industry is a pneumatic computer developed at the Academy of Sciences Institute of Automation and Remote Control. Operating by means of compressed air, it is far slower than an electronic device—times for a calculation are said to be half a second as against 1/100 000th sec—but for some applications in the oil, chemical and gas industries the extra speed of an electronic model may be unnecessary.

SHIPPING

New instruments aided Pole trip

Three separate systems of navigation were employed by the US atomic submarine *Nautilus* for the first underwater crossing of the North Pole, each being used to cross-check the other two. Firstly, there was the North American Aviation SINS (ship's inertia navigation system) a three-axis type which is the first of its kind in a combat ship. The basis of the other two systems—'Estimated' and 'Dead Reckoning'—was the in-

Technicians aboard the *Nautilus* check the operation of the inertial navigation system which helped to guide the submarine accurately for over three days under the ice

UNDER THE ARCTIC ICE. A US navyman carries out routine checks of the instruments on the *Nautilus* as she makes the first underwater crossing of the North Pole

formation provided by the Sperry gyro compass equipment comprising two types of naval gyro compass and an aircraft-type of directional gyro from the Sperry C.11 Gyrosyn compass, used as a low-wander rate 'free' gyro.

On his arrival at Portland the Navigating Officer of the *Nautilus*, Lt Shepherd M. Jenks, said the Sperry gyro compasses functioned perfectly normally up to a latitude of about 88° to 89° North, i.e. some 100 miles from the Pole, a remarkable performance for a gravity-controlled marine gyro compass. From 89°N inwards across the Pole to 89°N outwards, heading information was derived from the Gyrosyn compass functioning as a 'free' gyro. This compass was originally designed as a precision gyro-magnetic type for aircraft use with a free wander rate of the gyro of less than 0·5° an hour. It incorporates the new Sperry 'Rotorace' bearing technique which very substantially reduces friction errors in the gyro movement.

Originally developed for missiles

Lt Jenks reported that at the Pole itself the position established by all three systems of navigation corresponded exactly. Later, when he was able to take a 'solar fix' after 1830 miles (96 hours) submerged, the vessel's position was within less then 10 miles of that established by 'Dead Reckoning', 'Estimated' and the SINS. He also said the trip was planned before the ship was fitted with the inertial system in March, and that it was completely feasible on the basis of the Sperry gyro compasses and directional gyros fitted in the submarine. Also fitted in the *Nautilus* is a Sperry automatic course and depth keeping control system and a celestial altitude recorder which is used to monitor the other navigational systems.

Another point of interest is the length of time—73 hours under the ice—for which

the inertial system maintained its accuracy. Basically the inertial navigational equipment aboard the *Nautilus*—and its successor under the Pole, USS *Skate*—is similar to that developed for the North American Aviation guided missile SM-64 Navaho. Experience with the missile led to the application of the system, after minor modifications, in the US Navy's surface craft and submarines, and one such installation was recently tested on the experimental ship *Compass Island*. The SM-64 missile itself was abandoned just over a year ago, and the present success of the navigation system is an unexpected dividend of the programme.

—ELECTRONICS—

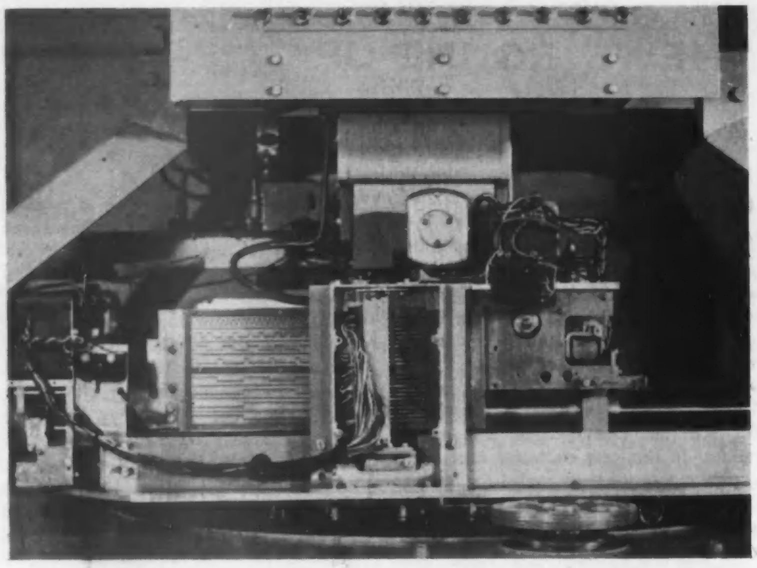
BTR move towards auto-assembly

Recent developments at the British Telecommunications Research centre at Taplow in Berkshire include an automatic component insertion machine, which is designed to assemble components of a wide range of sizes in printed wiring boards. It is still being worked on and few details of its construction are available, but a spokesman for the centre says that the machine carries components into hoppers and a programme punched into five-hole tape controls the complete process of selecting components from the hoppers, testing each component and inserting it into a printed circuit board. The machine represents a step forward in the evolutionary progress of automation in the electronic industry, and programming of both component value and positioning should ensure a high degree of flexibility.

A considerable amount of work on the automatic production of electronic subassemblies has been carried out in America, and the US Navy's 'MiniMech' machine —which is designed to select continuously any one of a number of components, transport it to a printed circuit and staple and solder it to the wafer—was tried out in a test production run recently.

Another new machine at BTR is an automatic numbering device which incorporates two tape reading heads and includes facilities for automatically inserting a message serial number and station call-sign. Coders for a test message ('Quick brown fox . . .') and a routine message of up to 40 characters are provided. The machine can carry out automatic transmission of call-signs and serial number at regular two-minute intervals when no traffic is being sent. The reading heads and coders are pulsed from an electronic distributor.

BTR is a research and development centre jointly sponsored by British Insulated Callender's Cables and Automatic Telephone and Electric Co, and both the automatic insertion and the auto-numbering transmitter were among the exhibits on show for a recent visit by the Radio and Telecommunication Section of the Institution of Electrical Engineers. Prominent among the displays were several adaptations of magnetic drum techniques: one device was a train time indicator, which on being given a date and destination by dialled code produced the time of the 'next train' on an illuminated panel.



AUTOMATION IN ELECTRONICS. Under development at British Telecommunications Research Ltd this programme-controlled machine will select and test components from hoppers and insert them into printed circuit boards

—NUCLEONICS—

Remote handling at Windscale

Two special power-operated manipulators have been developed for the continuous remote handling of spent fuel elements from the Calder Hall reactors. Designed and built by Savage & Parsons Ltd, for the Industrial Branch of the United Kingdom Atomic Energy Authority, they will be installed in the new 'pond' now being prepared by the AEA at Windscale.

The spent fuel elements, which are 43 in. long, over 2 in. in diameter and weigh 33 lb, will be loaded into baskets at the discharge points at each reactor and taken to the pond. The manipulators will transfer the 24 elements from each basket, one at a time, and pack them into railborne skips which will then be submerged immediately in water for periods up to six months to allow the short-lived activity to decay. Each manipulator is designed to handle up to 30 000 elements a year, the actual operation of transferring the contents of a basket to a skip taking approximately 30 minutes. As they will have come straight from inside the reactors, the fuel elements will not only be highly radioactive but will also have a temperature of approximately 160 deg.

The wall-mounted manipulator is a single vertical telescopic arm with shoulder, elbow and wrist movements, power-operated from a remote control unit. This is housed in a box with projecting handlebars —similar in appearance to the steering column of a motorcycle—and the operator sits at a metal desk with the box, which is mounted on gimbals, projecting 6 in. above the desk top. He can watch the movements of the arm and jaws through a zinc bromide window in the 5 ft thick shielding wall built round the pond, and move the manipulator arm away or towards the wall by pushing or pulling the control box; left and right movement of the manipulator forearm in the horizontal plane is obtained by pushing the control box sideways, so that the action is similar to that of an aircraft joystick.

TV eases Pluto operation

Operation of the reactor Pluto at the Atomic Energy Authority's establishment at Harwell will be helped in future by a closed circuit television system now installed. The cylindrical EMI Electronics camera unit, which measures only three inches in diameter and is approximately 48 in. long, is constructed so that it can be lowered through an inspection cover directly into the reactor's heavy water. It is protected by a transparent tube.

A remotely-controlled mirror mounted in front of the lens enables the operator to view all parts of the interior of the reactor, which has been specially illuminated. Switched scan reversal circuits have been incorporated in the camera control unit to compensate for reversal of the mirror's reflexion. Using the new system the operators can check over many of the reactor's components without removing them; this should save time and reduce radiation hazards.

TRAFFIC CONTROL

New device 'estimates' flow

A traffic controller which 'estimates' traffic conditions and automatically makes corresponding variations in the durations of signals given to vehicles is being shown at the Association of Public Lighting Engineers conference and exhibition to be held in Harrogate from 16th to 19th September. Three sets are already in action —two in London and one in Liverpool.

Vehicle-actuated signals have been playing a valuable role in the field of traffic control since their introduction to this country in 1932. The new controller, developed and manufactured by Automatic Telephone and Electric to the specification of the Ministry of Transport, is the latest step in the attempt to cope with the traffic problems caused by the ever-increasing numbers and speeds of vehicles. Most traffic congestion occurs at intersections, and it is designed to get the traffic through as fast as possible consistent with safety. It is, in fact, the vehicles themselves that largely control the timing operations carried out by the controller.

Normally the green signal is not given to any particular approach unless a demand for right-of-way has been registered by traffic passing over the appropriate detector. When granted the right-of-way, it will be given a *minimum* green period, whatever the traffic conditions may be. This period is determined by the number of vehicles known to be waiting between the stop line and the detector, and the automatic variation of the minimum green period in relation to the number of vehicles requiring it has the effect of reducing the 'cycle time' during periods of light traffic, thereby achieving a fast turnover from one approach to another without reducing the margin of safety. Vehicles crossing the detector *after* the start of the minimum green period set up for themselves 'extension periods' which can prolong the right-of-way up to the limit of the *maximum* green period.

The 'extension periods' can be either of fixed duration, or speed-timed. When speed-timed, the amount of the extension given to each vehicle is automatically varied in ratio to the speed at which the vehicle crosses the detector, allowing the vehicle sufficient time to clear the intersection before the signals change. The speed of a vehicle is calculated by the time taken by a wheel to travel the distance between the two channels of the detector. This speed-timing facility prevents the holding of the right-of-way by widely spaced vehicles while other traffic is waiting at a red signal. The idea is to speed up the phase changes, thus eliminating unnecessary waiting time, without reducing safety for slower vehicles.

AIRCRAFT

'Jet steering' guides Pye missile

Details of another anti-tank guided missile were released recently when Pye announced that they had produced a portable weapon. Like the Vickers 891 it is controlled by means of trailing wires, but the Pye missile employs a new type of guidance system which involves flight control by means of the alteration of the angle of thrust from the rocket engine. Both the weapons have been developed as private ventures. It is reported that the Army is not keen on the idea of control by wires and the only official project for an anti-tank missile, which is under development by Fairey Aviation, will probably not be dependent on this method.

The Pye missile is larger than the Vickers —comparative lengths are 5 ft and 3 ft— but it can still be just carried by one man. It has boost and sustainer rocket motors using solid fuel and can be launched from either a vehicle or from the ground by pressing a button. Control in flight is carried out by a small 'joystick' which the operator holds in his hands, and he follows the path by means of a pair of prismatic binoculars which can instantly be switched from low to high-powered magnification as the missile travels away from him.

The four wing-projections have no control surfaces for guiding flight: this is achieved

RIVAL ANTI-TANK MISSILES. The Pye (above) and Vickers 891 (below) guided missiles are both controlled by trailing wires: the Pye is heavier, more lethal, and uses a novel jet steering method but the Vickers can be carried in its canister easily by one man

by a jet steering technique. A stabilizing gyroscope is contained in the main body. Two of the wings carry wire bobbin fairings from which wires are paid out to the control box, and at the extremities of the other two are small pipes for producing tracking flares. Estimates of the cost of the complete missiles if put into production have been given as £1000 each.

In contrast to the Pye missile the Vickers 891 incorporates normal aerodynamic controls (four flaps are hinged to the trailing edges of the wings) and it can be carried in its canister easily by one man—combined weight is about 40 lb. It is controlled in flight by means of wires from a box incorporating an optical sight and thumbstick. The closed-loop control system is of the heading

type and is said to give accuracy with wide angular coverage.

Both Pye and Vickers missiles have been extensively tested and the companies are hoping to get Government support for selling the weapons overseas.

Control system simulates flight

A year ago, a research engineer who wanted to know how an air-conditioning system would behave in a climbing aircraft at 40 000 ft, would have had to take it up to the stratosphere to find out. Now, in a new programme-controlled test chamber at Hatfield, he can simulate conditions encountered during flight from take-off to touch-down. By means of an automatic control system, conditions in the altitude are made to follow those met throughout a particular flight, including, for military aircraft, climbs to operational height, combat, descent and landing.

The control system, consisting of seven sets of programme controllers, regulates the seven most important variables affecting air-conditioning units during flight. On each controller, the pointer indicating the set value for the variable rests against a revolving programme disk. By cutting the disk to a particular shape, the setting pointer can be made to move according to a predetermined flight-plan, and the controller interprets these movements of the setting pointer and changes the controlled variable accordingly. The flight-plan is easily changed by fitting a different programming disk. The addition of derivative action to some of the controllers provides a system of control which is, in theory, infinitely flexible, and can call for rates of change as high as any of those that can be expected to occur in flight—a vital factor when the most significant part of the test concerns the operation of equipment under transient conditions. In practice, the severity of the conditions that can be imposed on the equipment under test is limited only by the power at the controller's disposal.

Variables affecting aircraft systems in flight are regulated by the programme controllers on the wings of the console. Operators record the output information from the gauges in the centre panel

Of the seven programme controllers, two govern the temperature and pressure of the air simulating the pressurized supply to the cabin, as tapped from the engine compressors in the aircraft. Two more regulate the air supplied to the secondary circuit, and the remaining three control the independent altitude pressures—cabin altitude, secondary circuit discharge and ambient altitude. The whole programming cycle can be 'frozen' at any instant, in which case the controllers continue to maintain the set of conditions existing at that instant. The response of each controller can also be modulated by means of variable proportional and integral action, and the whole cycle can be slowed down to operate at any required speed.

Cheaper, more accurate testing

The chamber solves many aeronautical research problems, which have been growing steadily more acute since the war. Aircraft developments over the last ten years have made cabin air-conditioning a necessity, and at the same time exposed existing equipment to unknown conditions. While high-altitude flying opened up a new region of the upper atmosphere, where the behaviour of all kinds of equipment was open to question, new fighters appeared, powerful enough to reach a height of 36 000 ft from ground level in little more than a few seconds. For air-conditioning systems in particular, the use of jet-engine air substantially increased the number of variables that could significantly affect performance. All these factors presented research and development sections of the aircraft industry with an unmapped research field of great complexity, in which comprehensive flight testing was formidably expensive.

The Hatfield chamber is the result of an approach by de Havilland Propellers to Honeywell Controls. The idea was to design a test chamber in which a number of conditions could be regulated at will by an accurate and flexible control system. Pneumatic control was chosen for fast action, and a system was devised, enabling tests to be run to predetermined external conditions, repeatable to the last detail once the plant was set up for a given test.

After nine months of co-operation between the two companies, the chamber was built and tested. Careful dovetailing of chamber results with those obtained in flight established the validity of the method, and from this stage progress was rapid. According to a Honeywell Controls spokesman research data can be compiled more cheaply, more conveniently, and in many cases more accurately than in an aircraft during flight.

In this new test chamber the changing conditions of flight are accurately simulated by the control instruments at various points in the aircraft systems and components under test

METALS

New plant halves labour costs

The new central heat treatment plant now commissioned for Firth-Derihon Stampings Ltd at their Darley Dale works should bear comparison with any installation in Europe. It is designed to cope with large and small batch production of forgings of alloy and carbon steels, nickel-based and titanium alloys, ranging from a few ounces in weight up to about 800 pounds. The whole plant is heavily instrumented and mechanized.

The use of coke-fired producer gas plant —which needed too much maintenance— has been discontinued and the new factory runs on town gas. Several groups have had a hand in producing it: Gibbon Bros, Honeywell-Brown, Hartons, and members of the Brown-Firth research laboratory all collaborated. New plant installed includes three Gibbons dual-system heat treatment furnaces, two tempering furnaces and an oil quenching machine. By the use of more modern equipment, however, the maximum number of heat treatment furnaces in operation has been reduced by 75 pc, and the number of men employed is cut by half.

All the furnaces handle loads up to 5 tons and operate between 200 and 750°C; temperatures are electronically controlled by an automatic electropneumatic system, and the Honeywell-Brown instruments are housed in a central control room. Two-zone control is used for the tempering furnaces, and the dual-system types are single-zone controlled. The temperature distribution throughout the furnaces is held to extremely fine limits and is indicated and recorded at any six points in each furnace.

Compressed air supply for operation of the pneumatic control equipment is obtained from duplex air compressors and receiver

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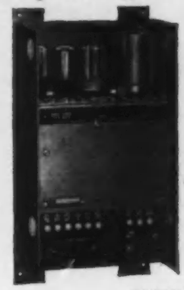

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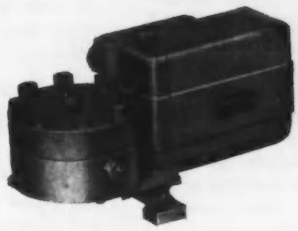

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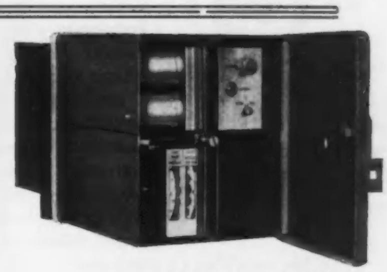

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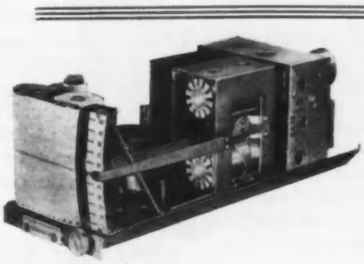

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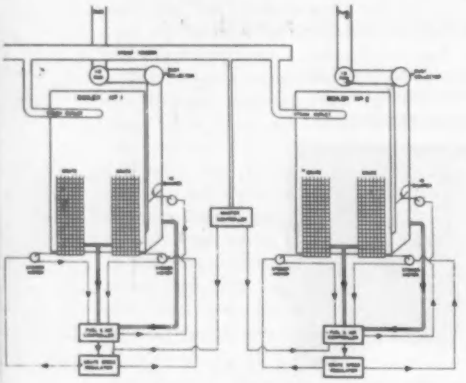
A member of the Elliott-Automation Group

units and actuation of these is automatically controlled via the instrument control room. Kent instruments are used to record gas-flow rates, and total gas consumptions of each furnace. The oil quenching machine is of advanced design, being of the fully enclosed type with automatic door operation. Automatic lowering and lifting of the load with variable-controlled oscillation of the load during the quench period is also incorporated. This ensures the optimum oil flow conditions during the quenching cycle.

———HEATING———

'Clean air' spurs industry

'Fuel efficiency and clean air are as inseparable as Siamese twins' said the Parliamentary Secretary to the Minister of Power recently. The Clean Air Act came into force in June and the Fuel



Kelvin & Hughes will show their automatic control for coal-fired boilers at the Fuel Efficiency Exhibition

Efficiency Exhibition, to be held at Olympia London, from 24th September to 3rd October, will give manufacturers of all sorts of heating equipment a chance to show what they can do.

One new exhibit will be a completely automatic boiler control installation by Kelvin & Hughes which has been specifically designed for shell type boilers and incorporates steam pressure (or high pressure hot water temperature) control and combustion regulation. Developed for the automatic maintenance of efficient combustion conditions, the equipment includes CO_2, temperature and smoke recorders, loss meters and a multi-point temperature indicator. A master control panel, designed for mounting remote from the boilers, contains a master pressure controller and a steam flow pressure recorder. A steam pressure control system for oil-fired boilers, which incorporates a specially developed phototransistor control circuit, will also be displayed.

A company that will emphasize its ability to offer pneumatic, hydraulic or electronic systems of boiler control is Electroflo Meters. Typical Electroflo automatic boiler control systems for all types of boiler will be demonstrated. These include the control and measurement of fluid flow, temperature and the rate of feed of solid fuel by means of flowmeters, pneumatic, hydraulic and electronic regulators and controllers, as well as pyrometers and potentiometers. In the latter field, the miniature Electroflo electronic potentiometer may be modified to emit a pneumatic signal, so introducing combined electronic and pneumatic control.

The main exhibits by Elliott Brothers (London) Ltd are two complete boiler control units in which standard Elliott and Bristol instruments are fitted for indication, recording, and automatic control. Instruments included cover the measurement of oil, steam and waterflows, temperatures, levels and pressures; measurement and control of draught; flue gas analysis, and overall heat-meter equipment. Pneumatic methods form a backbone of the display, but electrical control systems are also on show. Other exhibits on the stand of the Elliott-Automation group of companies will include instruments built into actual control consoles and panels to stress that the companies can offer a pretty comprehensive service of system design installation, commissioning and maintenance.

The range of components on view will be wide, including items like a new patented differential pressure switch by Black Automatic Controls (two diaphragms are incorporated and a specially developed lever system provides for operation at very small differentials and high pressures) and transistorized capacity-operated level control equipment by Lancashire Dynamo Electronic Products Ltd, which includes one with a probe assembly designed to operate up to 400°F.

——COMPONENTS——

Transistor experts to meet

An international convention on transistors and associated semiconductor devices is to be held in London from 25th to 29th May next year. Planned by the Radio and Telecommunication Section of the Institution of Electrical Engineers it will be the most comprehensive ever held on this subject, covering design, manufacture, materials, basic theory, characteristics, measurements, applications and equivalent circuits.

Within a decade of its invention the transistor has made its mark as the most significant development in electronics since the discovery of the valve, and the convention will provide a good opportunity for a large get-together of the experts. It is expected that at least 2000 will take part to discuss consolidation of past progress and the extension of applications. Summaries of papers should be sent in as soon as possible, and the deadline for complete manuscripts is 30th November.

———IN BRIEF———

Quality control. A wide range of analytical and control instruments designed by the US Consolidated Electrodynamics Corp for the oil, chemical, coal by-product and other industries is to be manufactured in this country by the Elliott-Automation group; a licence agreement was announced on the 8th of September.

Machine tool control EMI Electronics are to supply their control system to another two European companies—one in Italy and one in Holland.

Digital computers 1620 people visited the Ferranti London Computing Centre during the past year, and 78 firms carried out computations on a fee-paying basis.

B & K Laboratories A new centre to be opened in September at Tilney Street in Park Lane, London, will be used for films and a permanent show of international developments in electronic instrumentation.

A. Gallenkamp & Co This company is to act as sole agents in the United Kingdom for the range of continuous recording process instruments manufactured by Beckman Instruments Inc.

Philips Electrical Ltd The erection of a new building to house the headquarters of the South-West Region will begin shortly in the heart of the business centre of Bristol.

New digital computer techniques These will be discussed at Specialist Meetings which are to be organized by the committee of the Institution of Electrical Engineers' Measurement and Control Section on 16th and 17th February next year.

South Africa A new automatic telephone exchange now in operation in Johannesburg is equipped to cater for 7800 exchange line connexions, with capacity for five additional units—four of 7800 lines and one of 4000 lines. All the automatic equipment was supplied by Automatic Telephone and Electric Co.

United States The 'packaged' nuclear power reactor proposed for the US Army's cold weather training station at Fort Greely in Alaska is to have a completely transistorized instrument system. Valued at over $100 000 the equipment will measure all neutron levels in the reactor.

Italy Problems of instrumentation and automation in metallurgy, nuclear physics and electrical, mechanical and chemical engineering will be studied during the third Instrumentation and Automation Assembly from 22nd to 26th October. The Assembly is organized by the Federation of scientific and technical societies of Milan and an exhibition will run concurrently with the conference.

SELECTED BOOKS

Circuits, counters and cryotrons

Digital Computer Components and Circuits *by* **R. K. Richards.** *Van Nostrand. 1958. 511 pp. £3 4s.*

As digital methods are being used increasingly in control engineering, the design engineer in this field as well as the digital computer circuit designer will find this book a very useful addition to his reference library. It contains a general survey of the components and circuit configurations which have been developed for use in digital computers. It is suitable either as an introduction to the field or as a handbook for the engineer already familiar with the subject.

The first chapter is a short introduction and history of the subject and brings out the more important emphases which are peculiar to circuit design for digital computers. Diode switching circuits and systems of circuit logic with valves, transistors or rectangular hysteresis-loop magnetic cores are fully discussed. Many storage devices are described briefly while the systems employing storage on a magnetic surface and magnetic cores, both of which are now widely used, are given more detailed discussion. A new development of great promise, the cryotron, which utilizes the phenomenon of superconductivity, is included among the miscellaneous components. One chapter is devoted to the various methods of decimal counting such as ring counters, cold-cathode tubes and the electrostatic beam-deflexion tube. The final chapter in which digital-to-analogue and analogue-to-digital convertors are discussed is of more direct interest to the control engineer.

Design details are rarely given, but, when required, more detailed information will be found in the references contained in the comprehensive bibliographies at the end of each chapter. The adequate index increases the usefulness of the book as a source of reference.

R. RENWICK

From linear to non-linear

Non-linear Control System *by* **R. L. Cosgriff.** *McGraw-Hill. 1958. 366 pp. £3 10s.*

This book will be useful to the engineer already having a knowledge of the theory of linear systems, who becomes concerned with the performance and design of non-linear systems. Although the author suggests in the preface that an extensive background is not required for a study of this textbook, it appears to the reviewer to be especially suitable for postgraduate courses in control engineering. Many worked examples are given in the text.

The earlier chapters describe the simple attributes of control systems, their development and their representation by block diagrams. The theory of linear control systems is then developed, the solutions of the differential equations being discussed in terms of the characteristic modes of the response. This is followed by the block-diagram representation of the system response, which is a good physical interpretation of the partial-fraction solution of the transform equations. The frequency response of linear systems is then discussed using the inverse transfer function.

The introductory chapters on the theory of non-linear systems treat small signal theory and the general linear methods for non-linear systems. The analysis of the effects of static friction, coulomb friction and backlash is well treated; examples are given showing the effect of non-linear friction on the performance of a servomechanism. The operation of relays, which forms an important part of non-linear control theory, is discussed in detail. Phase-plane techniques are described and used to determine the performance of control systems with non-linearities present. The author shows only theoretical trajectories; he could with advantage have included trajectories obtained experimentally from typical systems. A detailed description of the frequency-response method of investi-

gating non-linear systems using the describing function includes a comprehensive account of the method's limitations.

The later chapters deal with the application of statistical methods and logic switching circuits to control systems. A whole range of topics is treated, and the author gives many references to enable the reader to study those topics of particular interest.

The book is well produced, with good diagrams.

J. V. PARRY

Crystal history

***Transistor Technology Volume I** by **Bridgers, Scaff and Shive.** Van Nostrand. 1958. 698 pp. £6 11s. 6d.*

'Transistor Technology' is the first of three volumes to be written by members of the Bell Telephone Laboratories, describing the methods of manufacture and testing of transistors. The series is written with a historical approach, and consequently the first volume deals principally with germanium point-contact and grown-junction transistors.

The first section treats the purification of germanium and its growth into single crystals, together with methods of producing grown junctions and the control equipment necessary for this. In the second section the authors describe the design and fabrication of transistors, including the evaluation of germanium material, preparation of components and encapsulation. The last part of the book deals with device testing and characterization.

From a historical viewpoint the book has a certain value, and it may be useful to those working with transistors who want to know more about their beginnings. Although some interesting technical information is given, the work could on the whole be confusing to a beginner who has no idea where the present emphasis lies. For example, much of the section on device fabrication is out of date. If the next volumes can bring the subject more nearly up to the present day, the series will form a useful reference work.

M. SMOLLETT

Heavyweight—but little control

***Van Nostrand's Scientific Encyclopedia.** Van Nostrand. 3rd Edition, 1958. 1846 pp. £11.*

This is in most ways an admirable work—unquestionably the best scientific and technical encyclopedia at present available in the English language. Perhaps it bites off more than can be properly chewed in one volume, albeit about as large as a book can conveniently be, measuring 11¼ in. by 8½ in. by 3 in., and weighing 8½ lb. One almost needs a lectern to use it properly. The third edition has been brought up to date (end of 1957) and contains about 15 000 entries; these are not only on the pure biological and physical sciences but also on medicine, mathematics, engineering and photography. The text is clear and authoritative with an abundance of cross-references in bold type, and there are many helpful line diagrams. Moreover a number of full colour plates (not indexed) add excitement to turning the pages of the work and give it the feel of a book to look at rather than refer to. The engineering coverage is well exemplified by the allotment of a whole page to *forging*, one-and-a-half pages to *landing gear*, *airplane*, and four pages to *boilers*, but mathematics and physics are not skimped. Contrariwise, control engineering is not recognized as such by the editors, and the subject does not win many detailed entries. While *automation*, *feedback*, *guided missiles*, *servomechanism* and *flowmeter* are adequately discussed, it is surprising not to see entries for *pick-off*, *pneumatic control*, *transfer function*, *swash plate*, *actuator* and *data-processing*, and to find that *hunting* is applicable only to rotating mechanisms.

However the control engineer would not expect the encyclopedia to inform him about control engineering. On a wider quest, I tested it at random with the following subjects: *prestressed concrete*, *neutrino*, *Curie point*, *synapse*, *nuclide*, *blepharitis*, *homeostasis* and *alychne*. It included the first five but not the others. Perhaps this result will give some indication of the detail to be expected. One must hope that in the next edition the work will be published in two volumes, for division into biological and physical sciences would allow more entries and make two more tractable books.

C. T. RIVINGTON

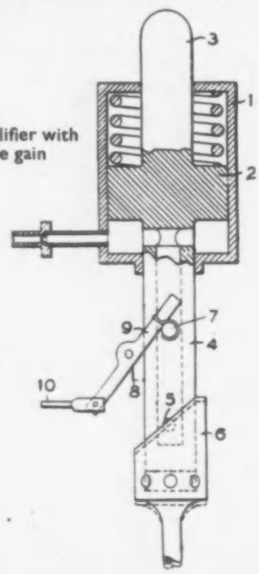
INVENTIONS *notes on recent patents in the control field*

New pressure amplifier

It is claimed that a single-stage variable-gain fluid pressure amplifier has not hitherto been available, and that such an amplifier would have wide applications in hydraulic and pneumatic control and would eliminate the necessity of designing a specific amplifier for each application. Further the amplifier may be used as a computer element to multiply an input and a gain varying signal. The drawing shows one embodiment, indicating the cylinder (1) and the piston (2), which has an output shaft (3) and a hollow input shaft (4). The lower end of the central hollow passage has an outlet port (5) over which slides a cup-shaped valve (6). A cam follower (7) on the input shaft is kept in engagement with the cam surface (8) by a spring. The slope of the lever (9) can be adjusted by an actuating rod (10).

Normally the amplifier is balanced with fluid entering at the side of the cylinder and passing down the hollow passage to be exhausted at the outlet port; the cylinder taking up an equilibrium position. If the cup-shaped valve is moved upwards to cover the outlet port, then the fluid pressure inside the passage will rise and the piston will move upwards until the outlet port is uncovered sufficiently for equilibrium. Because of the cam and its follower the

A fluid amplifier with variable gain

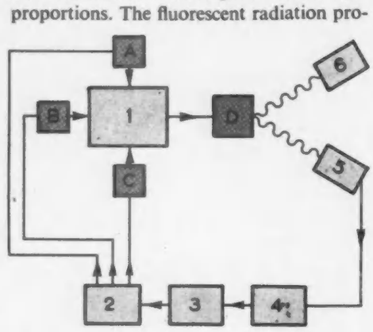


upward movement of the piston is not straight but helical, and so a movement amplification as well as a pressure amplification is given to the output shaft. The action is reversible, and instead of being spring-loaded the piston may be double-acting. The degree of amplification is decided by the slope of the cam surface (8), whose shape may be so chosen that the output shaft follows any desired function of the input movement given to the cup-shaped valve. If a signal is given to the actuating rod as well as to the cup-shaped valve, then the movement of the output shaft is proportional to the product of the two signals.

796 537. Fluid-pressure servomotor-control systems. **General Electric Co.** 11th June 1958.

Sophisticated mixing

A product D is bombarded with X-rays in the process of ensuring that its constituents A, B and C are mixed together in the right proportions. The fluorescent radiation pro-



A, B and C are mixed in their correct proportions to form D

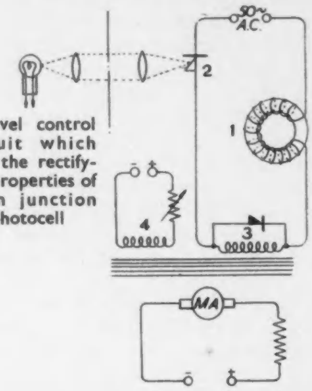
1 Mixer
2 Servomechanism
3 Computer
4 N-channel pulse amplitude analyser
5 Proportional counter
6 X-ray source

duced is fed to a N-channel pulse amplitude analyser which sorts the pulses according to their amplitude and feeds the respective pulses to a computer. The computer supplies information to a servomechanism if there is any deviation from the correct amount in the number of pulses per second received from each channel of the analyser, and this servomechanism adjusts the rate of feed accordingly.

791 088. Automatic control of chemical &c processes.

Photosensitive control

This patent is concerned with a circuit which will control a load according to the light which falls upon a photocell. In the diagram is shown an arrangement by which the circuit can be used to control the level of a liquid. The toroidal winding (1) has a core of 'Permalloy' and is in series with the a.c. supply, a p-n junction germanium photocell (2), and one field (3) of a split field servomotor. The other field (4) of the servomotor is energized by a d.c. supply as is the motor armature. The light falling on the photocell will be varied by a shutter which moves with the liquid level. When the level is correct the photocell is illuminated and has a low resistance in both directions, so that the amplitude of the current is not sufficient



A level control circuit which uses the rectifying properties of a p-n junction photocell

to saturate the core (1). If the light source is blocked the photocell will act as a rectifier and the coil will be saturated, thus reducing its impedance. A heavy current will flow in the motor field (3) to drive the servomotor and to reposition the shutter.

793 523. Automatic fluid level control systems. **Standard Telephones & Cables Ltd.** 16th April 1958.

Programming by tape

An automatic programming system uses a punched tape to set the value of a temperature and the time for which it must be maintained. The information is contained in six rows, the first three giving the temperature, and the second three the process time. Each row has five holes, the first four representing the numbers 1, 2, 4 and 8, and the last provides the stepping-on signal. The tape is stepped until the six rows have been scanned, and then it is held until the time required for that particular temperature has elapsed, when it will scan the next six lines. The value of the temperature is stored in selected resistors which form one arm of a bridge circuit. If the bridge is unbalanced, it means that the desired temperature is not the same as the actual, which forms another arm of the bridge. The unbalance is used to control the temperature. The time is stored in another unit. A particular use of the programme system, which might be expected to run for several days, would be in the control of electric furnaces.

797 419. Switching systems. **English Electric Co Ltd.** 2nd July 1958.

These abstracts are made from British Patent Specifications with the permission of the Controller of Her Majesty's Stationery Office. Complete specifications can be obtained from the Patent Office (Sales Branch), 25 Southampton Street, London, WC2. Price 3s. 6d. a copy (including postage, inland and abroad)